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Special Issue On Soil Quality

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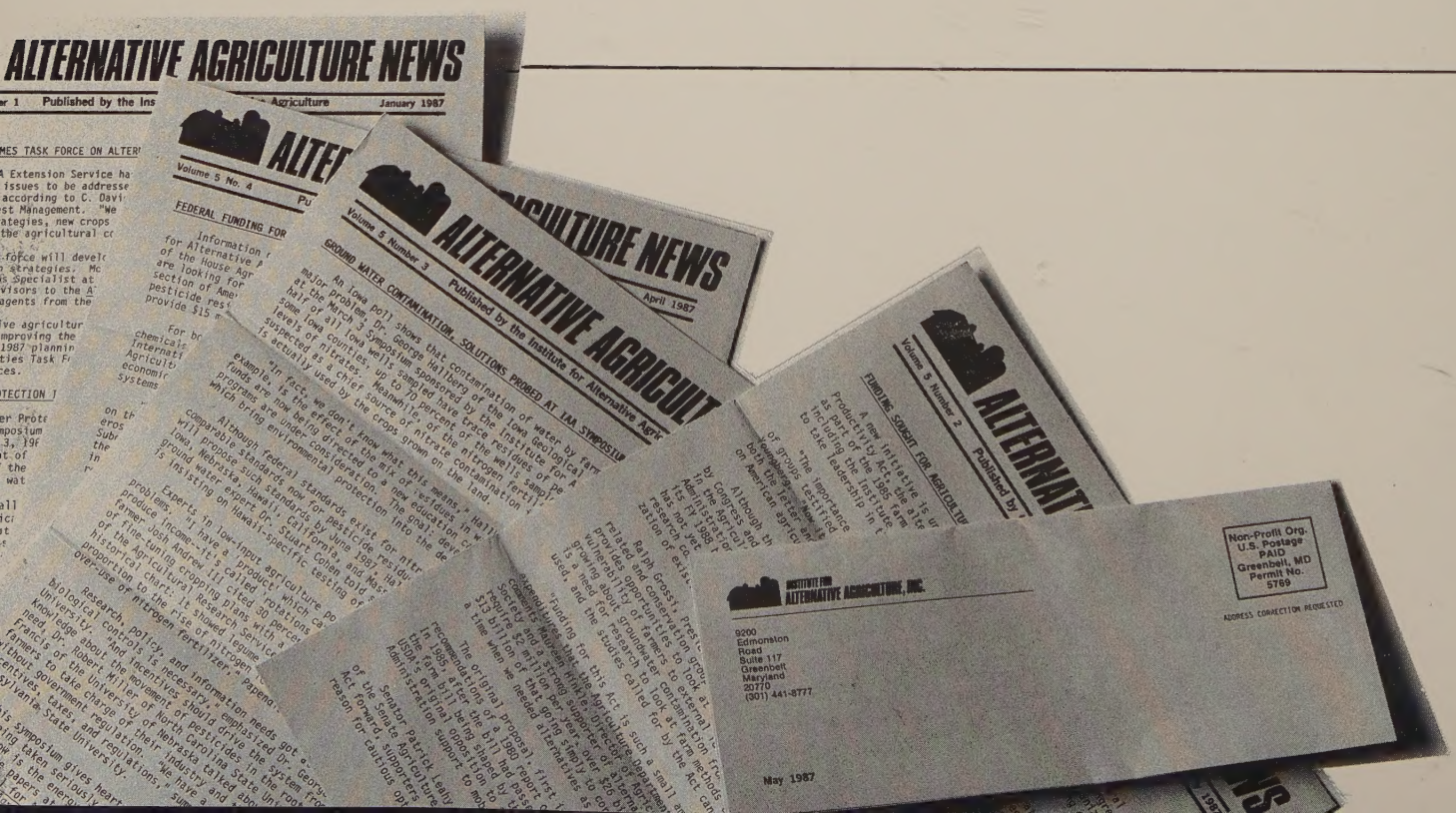
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Institute Information

The Institute for Alternative Agriculture is a nonprofit, tax-exempt research and education organization established in 1983 to encourage and facilitate the adoption of low-cost, resource-conserving and environmentally-sound farming methods. It works closely with producer groups, public research and education institutions, and government agencies in promoting a sustainable agriculture system.

Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

The cover illustration by AADVARK, Inc., Sterling, Virginia, portrays the soil as a living system comprised of a matrix of mineral and organic material, air, water, and various beneficial microorganisms and macroorganisms. The activities of these organisms can enhance soil quality through biological nitrogen fixation, suppression of pathogens and diseases, improved soil aggregation and structure, decomposition of organic wastes, nutrient cycling, and increased aeration and permeability. These activities are vital to the development and maintenance of healthy and high quality soils for a more sustainable agriculture that will ensure the production of abundant, safe, and nutritious food and fiber both today and for future generations.

FROM THE EDITOR

From its inception, the Institute for Alternative Agriculture has regarded soil quality as a key issue related to the sustainability of agriculture. Development of evaluation criteria for soil quality can lead to enlightened policy-making, improved education programs, and farming practices designed to enhance our soil resources throughout the world. The papers in this special issue present some of the first conceptual perspectives on the nature and importance of soil quality. It is our hope that they will contribute to a new and vigorous discussion in what we view as an evolutionary process aimed at developing and refining our understanding of soil quality as an underlying foundation for agricultural sustainability.

The Institute commends the Rodale Institute for its foresight and leadership in initiating this dialog on the need to document changes in soil quality and soil resources on a global scale. The July 1991 conference, which was made possible largely through their support, coupled with the papers from that conference which appear here, are major steps in that direction.

This is the third time we have included two Journal numbers in a single issue. As before, the material included here greatly exceeded the Journal's normal length. In our view, publishing these papers in separate issues would have made it difficult to retain the sense of wholeness represented by the 10 papers that form this special issue.

We note that the additional research articles and commentaries found in these pages stand apart from this issue's emphasis on soil quality. Nonetheless, these analyses of additional aspects and issues of agricultural sustainability serve as reminders of the scope and complexity of this profoundly important subject.

Finally, we wish to thank Drs. James F. Parr and Robert I. Papendick for their outstanding leadership in making this special issue possible.

I. Garth Youngberg
Editor

Soil quality—The key to a sustainable agriculture

Soil is the world's most vital component for food and fiber production: preservation of this critical natural resource is paramount for protecting the environment, and ensuring that current and future populations are healthy and well-fed. In many countries of the world, including the United States, soils are being degraded at an alarming rate by wind and water erosion, desertification, and salinization resulting from misuse and improper farming practices. Often the topsoil is lost at a rate that far exceeds the capacity of natural processes to regenerate it. With soil degradation, there is a concomitant decline in soil quality, i.e., the soil's capacity to produce healthy and nutritious crops, resist erosion, and reduce the impact of environmental stresses on plants. Many decades of research have consistently shown that the best means of improving and restoring soil quality and productivity is by proper and regular additions of organic materials mainly through the use of crop rotations, cover crops, crop residues, animal manures, composts, and reduced tillage.

Presently, there is no scientifically acceptable method or procedure for quantifying and measuring the attributes of soil quality so that the effects of management practices could be evaluated on a field, watershed or regional scale. If properly characterized, soil quality should serve as an indicator of the soil's capacity to produce safe and nutritious food, to enhance human and animal health, and to overcome degradative processes. A quantitative assessment of soil quality could provide much needed information on the adequacy of the world's soil resource base in relation to the food and fiber needs of a growing world population. It would also allow governments to formulate realistic food policies and to allocate scarce resources for programs that would conserve, protect and improve the quality of agricultural soils throughout the world.

The goal of agricultural sustainability relates directly to maintaining a healthy soil that is resilient to stresses imposed on it either by natural forces or farming practices. But how can soil quality and its changes due to management practices be evaluated so that steps can be recommended that will regenerate and sustain this vital resource? It was in response to this critical need that the Rodale Institute Research Center sponsored and convened a workshop on Assessment and Monitoring of Soil Quality during July 11-13, 1991, in Emmaus, Pennsylvania. The critical importance of nuturing the concept of soil quality and soil health was emphasized by John Haberern, President of the Rodale Institute, in his opening remarks.

The themes addressed by speakers representing national and international agencies, institutions and universities included the relevance of soil quality to agriculture and the environment, a global assessment of soil degradation, criteria for characterizing soil quality and its attributes, and prospects for developing useful soil quality indices.

In their opening paper, Parr et al. emphasize that the attributes of soil quality should not be limited to soil productivity and its rate

of change but must be expanded to include environmental quality, human and animal health, and food safety and quality. Soil quality can be sustained or enhanced only if degradative processes are offset or reduced by processes or inputs that improve or rehabilitate the soil. The need for developing a soil quality index based on local and regional considerations is addressed in the paper by Granatstein and Bezdicek. The challenge according to these authors is to integrate soil parameters into a meaningful index that correlates with soil productivity, environmental quality, and health.

The paper by Sanders discusses recent international activities that have been directed toward assessing and monitoring soil degradation. Some of these studies have identified many of the practical problems of measuring land degradation, data collection, and analysis that will have to be resolved before sufficiently accurate procedures are developed. A complimentary paper on the subject of global soil degradation is presented by Sumner and Miller on how soil crusting contributes to the severity of soil erosion, nutrient runoff and impaired seedling emergence. Some interesting strategies for alleviating soil crusting are discussed.

Two papers in this special issue focus on soil biological criteria as indicators of soil quality, an area that has been somewhat neglected compared with the rather extensive characterization of soil chemical and physical properties. Visser and Parkinson discuss the potential role of soil microorganisms as indicators of soil quality, while Stork and Eggleton suggest how the diversity of soil invertebrate fauna could also be used advantageously for this purpose.

The physical and chemical attributes needed for proper characterization of soil quality are presented by Arshad and Coen. They discuss the justification for selecting and measuring specific attributes of soil quality, and for monitoring changes in soil productivity. Karlen et al. enumerate various soil and crop management practices and how they might affect different soil quality indicators. They conclude that the most important consideration in improving and sustaining soil quality is to maintain an adequate level of soil organic carbon through crop rotations and recycling of organic wastes.

The factors that can affect the nutritional quality of crops, including soil factors, climate, the cultivar, and fertilizer management practices, are reviewed in the paper by Hornick. These and other factors are discussed with respect to food safety and quality, and their implications for human and animal health.

Finally, we wish to thank Drs. M. A. Arshad and L. F. Elliott for their assistance in reviewing the manuscripts in this special issue, as well as the anonymous reviewers who contributed generously of their time and talent. We also acknowledge and thank Dr. William Lockeretz for his excellent editorial assistance.

Robert I. Papendick
James F. Parr

OPINION

Coming full circle —The new emphasis on soil quality

John Haberern

Back in 1942, Rodale Press founder J. I. Rodale made a simple, but profound prediction about an impending revolution. A gentle revolution, to be sure. But one that would shake the very roots and foundations of our agricultural research and education system. One that would tie farmers and farming directly into our health care system.

"I believe a whole new era of agricultural research is in the making—one which will benefit the country at large far more than all the research of the past has done," J. I. said fifty years ago. "One that will clearly help create a healthy society and a country of prosperous farms and a healthy, vigorous people."

What J. I. foresaw was a soil-care revolution. A time when our agricultural leaders, scientists, farmers, and yes even consumers, would finally wake up to the fact that for far too long we've been treating our soils like dirt. A time when agricultural research would rivet in on a new baseline—soil quality—in balance with the priority now given to production and higher yields.

But even more important than that, what J. I. and his son, Bob Rodale saw over the horizon was a willingness of the agricultural community to go even one step further: to recognize that the health of the people and the health of the soil were closely intertwined. From the moment people first scratched the earth and sowed seeds, they've had the power to improve their food, and by extension, their health, by what they did or did not do to the soil.

Unfortunately, in my estimation, the soil-care revolution is still in the starting blocks. Granted, we are taking small, but significant steps toward finally recognizing that the health of the soil is just as important as the health of our air and water. Building soil fertility

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and recognizing the need to monitor the health of the world's soils over time is now on the agendas of various private and public institutions.

Much credit for this must go to USDA's Agricultural Research Service, Rodale Institute, the World Sustainable Agriculture Association and other non-profits, USDA's Soil Tilth Lab, some land grant universities, and a few forward-thinking private foundations. All have come to the same conclusion: we truly have no idea what kind of shape the world's soils are in. We've been driving along in a car without a fuel gauge for far too many years now. We may have three-quarters of a tank left, or we may well be running on empty. We simply have no idea.

That will change. In less than five years, I predict we will have a soil health index, a report card documenting the gains and losses in soil quality worldwide. Such an index will help target more focused agricultural research well into the 21st Century.

But why all the fuss about soil quality anyway? Losing 24 billion tons of rich productive topsoil each year certainly would be reason enough to call a halt to business as usual. Then there are the additional costs to society resulting from the side effects of soil erosion. Certainly no drop in the bucket. No need here to go into the long litany of other abuses we've heaped on our soils.

But for me, the real reason we should all be concerned about the deteriorating health of the world's soils is directly related to the health care crisis staring us in the face today. Fifty years ago, J. I. Rodale predicted such a crisis and said then that we can head it off by preventing diseases rather than treating them. His prevention solution: Improve the quality of foods people eat by improving the health of the soils in which they are produced. He put his money where his mouth was and founded The Soil & Health Foundation—forerunner of today's Rodale Institute—to "conduct, engage in, foster, and encourage scientific research and study, teaching, training, informing and educating the public on and concerning the soil, foods, and the health of man, and their relationship to each other."

In 1987, Bob Rodale reinforced his father's conviction with this pronouncement: "Our feeling is that prevention is by far the most effective and affordable approach to health. When you think that way, when health is seen primarily as a challenge of prevention, then the solution to health problems become largely agriculture solutions. Better foods produced in a better way, in a regenerative, soil enhancing way, is essential to prevention of disease."

Actually, a USDA lab, the former Bureau of Chemistry and Soils—vintage early 1930's—came close to reaching that same conclusion. Close, but not close enough in terms of stretching the soil health—human health envelope. In 1937 a research chemist by the name of Kenneth C. Beeson was assigned by the Bureau to "begin reviewing world literature on the link between nutritional value of foods and the quality of the soil in which the food was grown." According to Beeson, a number of people in agricultural experiment stations were analyzing garden produce and finding, for example, that lettuce in Florida might have a different calcium content than lettuce grown in Mississippi.

Beeson went on to head a new lab at Cornell, called the Plants, Soils, and Nutrition Lab. Its mission: "trace the nutritional connection between soils, plants, and animals." The idea was that improvement to the soils might send beneficial ripples all the way up the food chain.

What an off-the wall idea! In fact, Beeson said, "The concept behind the Ithaca lab—the thought that soils could effect the plants that sprouted in them—was considered quite novel in the 1930's." However, after Beeson's tenure as director, the Ithaca lab pretty much dropped the ball.

Who will come to the rescue? Farmers, I say. While the revolution J. I. predicted has yet to come to full fruition, its seeds have found fertile ground in the fields of innovative farmers and researchers who understand the importance of healthy soil. Farmers will be the soil health—human health heroes of the future. To them, sustainable agriculture means more than just maintaining nutrient levels. In the words of North Dakota farmer and sustainable agriculture leader Fred Kirschenmann, "From a sustainable perspective, the condition of the soil is at least as important as its fertility. This means being concerned not just with what is missing from the soil, but also what is wrong with it, and what can be done to correct it."

For sustainable farmers, soil management goes far beyond deciding how much fertilizer to apply. They rely on a combination of complex rotations, manure and compost applications, carefully managed tillage and other practices to insure optimum soil health. Take, for example, the practice of cover cropping. Legume cover crops can supply nitrogen to following crops, but the benefits of cover crops go far beyond simple fertilizer application.

Cover crops can also improve soil structure, helping soils drain in wet years yet hold moisture during drought. Better structure can also help reduce compaction from field traffic. Cover crops can soak up excess nitrogen in the soil preventing it from leaching to groundwater, and deep-rooted plant species can bring nutrients to the surface, making them more available to following crops. Farmers who have successfully incorporated cover crops into their cropping systems also report increases in soil organic matter and more efficient nutrient cycling. Soil microbiology research is only beginning to explain why.

Regenerative farmers are reaping the benefits of cover cropping and other practices that promote soil health, even though those benefits can't always be identified by basic soil tests or simple economic analyses.

In addition, the benefits extend beyond the farm gate. Attention to soil health helps reduce the need for chemical pesticides and fertilizers and their attendant potential for pollution. Many also maintain that, in addition to the lack of pesticide residues, the nutritional quality of crops produced in healthy soils is superior, leading to healthier livestock and healthier people.

What a novel idea! Many years ago Bob Rodale said, "Farmers are the health care practitioners of tomorrow." Bob, liking to shake the status quo, often made predictions like that. Statements that, at first glance, might seem to be a little absurd. Then, after consideration, the truth of the statement slams home!

What Bob said is becoming evident today. Because farmers are the source of the nutrients we all need every day to stay alive, let alone thrive. What they do on the lands they till effects the health and well-being of all the world's people.

Certainly, I'm not blind to the fact that there are other instrumental factors interacting to determine personal health. Yet, now is the time to position farmers on a much higher plane in terms of their role in enhancing the health of present and future generations.

Soil quality: Attributes and relationship to alternative and sustainable agriculture

J.F. Parr, R.I. Papendick, S.B. Hornick, and R.E. Meyer

Abstract. *Different chemical, physical, and biological properties of a soil interact in complex ways that determine its potential fitness or capacity to produce healthy and nutritious crops. The integration of these properties and the resulting level of productivity often is referred to as "soil quality." Soil quality can be defined as an inherent attribute of a soil that is inferred from its specific characteristics and observations (e.g., compactability, erodibility, and fertility). The term also refers to the soil's structural integrity, which imparts resistance to erosion, and to the loss of plant nutrients and organic matter. Soil quality often is related to soil degradation, which can be defined as the time rate of change in soil quality.*

Soil quality should not be limited to soil productivity, but should encompass environmental quality, human and animal health, and food safety and quality. There is inadequate reliable information on how changes in soil quality directly affect food quality, or indirectly affect human and animal health. In characterizing soil quality, biological properties have received less emphasis than chemical and physical properties, because their effects are difficult to measure, predict, or quantify. Improved soil quality often is indicated by increased infiltration, aeration, macropores, aggregate size, aggregate stability, and soil organic matter, and by decreased bulk density, soil resistance, erosion, and nutrient runoff. These are useful, but future research should seek to identify and quantify reliable and meaningful biological/ecological indicators of soil quality, such as total species diversity or genetic diversity of beneficial soil microorganisms, insects, and animals.

Because these biological/ecological indexes of soil quality are dynamic, they will require effective monitoring and assessment programs to develop appropriate databases for research and technology transfer. We need to know how such indexes are affected by management inputs, whether they can serve as early warning indicators of soil degradation, and how they relate to the sustainability of agricultural systems.

Keywords: global change, soil erosion, soil degradation

Introduction

The 1980s became the "decade of awareness" that the productivity of agricultural soils worldwide was in general decline. Food grain production per capita decreased significantly in some parts of sub-Saharan Africa, the Near East, and Asia during that decade. Although some of this decline was due to increased population growth and periodic drought, much of it occurred because of poor management and exploitive farming practices, and with them the degradation of agricultural lands by wind and water erosion, nutrient depletion, and the loss of soil productivity (Food and Agriculture Organization, 1986; Parr et al., 1990; Dregne, 1992). In the United States, soil erosion by wind and water, and the associated loss of soil productivity and damage to soil quality, continue to be our most serious agricultural and environmental problems (Larson et al., 1990).

Erosion causes the world's topsoil to be lost at an estimated 0.7% per year (Brown and Wolf, 1984). This is cause for concern because intensive, high yielding crop production requires mineral nutrients in this layer that may not be easily replaced by fertilizers alone. Where the topsoil has been entirely removed, or where it has been severely eroded, crop yields are from 20 to 65% lower than on non-eroded soils (Langdale et al., 1979; Massee, 1990). Less than 12% of the earth's total land surface is currently cultivated, and little additional arable land is available (Smith and Paul, 1990).

Agricultural productivity depends largely on the topsoil, the uppermost layer, which is about 15 to 20 cm deep for most soils. Topsoil serves many functions. It provides a rooting zone for plants, supplies a balanced mix of plant nutrients, and retains, stores and releases moisture for plant use. It also enhances seed germination and root penetration, and supports a complex community of beneficial microorganisms that decompose organic wastes, recycle plant nutrients, and protect plants from pests. All these functions are essential for maintaining the tilth, fertility and productivity of agricultural soils; soils with these capabilities are considered by many to be "healthy soils."

Recently, Haberern (1992) introduced the idea of a "Soil Health Index" to characterize a soil's capability for sustainable production of healthy and nutritious crops. He likened this to a "report card" that

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would document the gains and losses in soil quality as they are affected by management practices. The purposes of this paper are: to explore the components of soil quality; to discuss how they relate to alternative and sustainable agriculture; and to consider how soil quality might be quantified to indicate the status of soil health and provide an early warning of soil degradation and the need for remedial measures.

An Emerging Crisis

A crisis has emerged, especially during the past decade, in which we must make decisions concerning the state of the world's soil resource base. There is a strong consensus that we no longer can tolerate extensive soil degradation and loss of productivity (Brown and Wolf, 1984; Oldeman et al., 1990). Gibbons and Wilson (1984) concluded that because of poor management and exploitive agricultural practices, many U.S. farmers do "treat their soils like dirt."

The collapse of early civilizations in the Near East and North Africa have been attributed mainly to the degradation of agricultural soils by excessive erosion, siltation, and salinization (Lowdermilk, 1953). Even today, soil degradation is the single most destructive force diminishing the world's soil resource base. Because of this, some countries have already experienced increased food costs and acute food shortages; however, too few people have related this to the loss of soil quality. Action is needed to sensitize governments in both developed and developing countries to the grim consequences of soil degradation, and to encourage national and regional programs that will conserve and enhance soil quality on a global scale. Brown and Wolf (1984) concluded that the soil erosion crisis must be viewed in a global context because the production, distribution, and consumption of food is part of the global economy. They emphasized that if the loss of topsoil continues, it will lead to acute economic destabilization worldwide.

Some would argue that agricultural soils should be regarded as similar to the world's oil reserves. Both are valuable natural resources that are being depleted at alarming rates, but they should be conserved and used much more efficiently. Until now, there has been far greater worldwide awareness and concern about the rate of oil depletion than about the rate and significance of soil degradation and loss of productivity. This situation could change as we address such issues as increased population growth, global warming, food production deficits, environmental pollution, and quality of human life in the years ahead.

The Concept of Soil Quality

Various physical, chemical, and biological properties interact in complex ways that determine a soil's potential fitness for sustained production of healthy and nutritious crops. The integration of growth-enhancing factors that make a soil productive has often been referred to as "soil quality." The Soil Science Society of America (1984) defines soil quality as an inherent attribute of a soil that is inferred from soil characteristics or indirect observations (e.g., compactability, erodibility, and fertility). Thus, soil quality has traditionally focused on, and has been equated with, soil productivity. More recently, the concept of soil quality has been broadened to include attributes of food safety and quality, human and animal health, and environmental quality, as shown in Figure 1. Soil quality therefore might be defined this way: The capability of a soil to produce safe and nutritious crops in a sustained manner over the long-term, and to enhance human and animal health, without impairing the natural resource base or harming the environment.

The soil serves as an environmental filter for removing undesirable solid and gaseous constituents from air and water. Almost all recycling of organic materials, and the retention and release of water and nutrients for plants and soil organisms, occurs in the soil and is enhanced by a biologically-active and healthy soil. Although not well understood, soil quality may also play a major role in plant health and in the nutritional quality of the food that is produced. Thus, if properly characterized, soil quality should serve as an indicator of change in both the soil's ability to produce optimum levels of safe and nutritious food, and its structural and biological integrity, which in turn is related to the status of certain degradative processes and to environmental and biological plant stresses.

Some people believe that good quality soils are essential for producing healthy and nutritious crops that in turn can en-

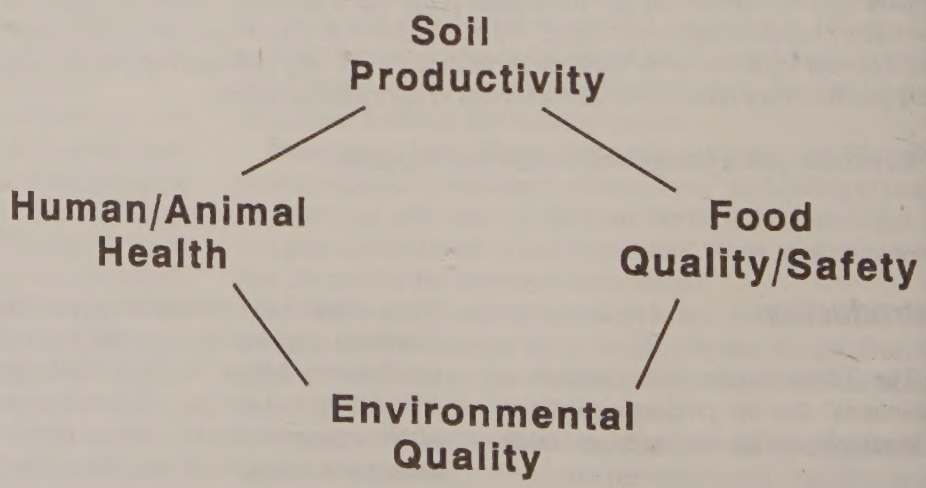

Figure 1. Attributes of soil quality.

hance human and animal health. Figure 1 suggests such a linkage, but research is needed to verify this relationship.

Soil quality can decline from many causes: not just wind and water erosion, but also such degradative processes as nutrient losses from runoff and leaching, depletion of soil organic matter, crusting, compaction and desertification; it also can occur through the accumulation of toxic substances from excessive use of chemical fertilizers and pesticides, and atmospheric deposition or improper waste disposal (Sampson, 1981; Hornick and Parr, 1987). The maintenance or restoration of soil quality is highly dependent on organic matter and an array of beneficial macroorganisms and microorganisms that it supports. Proper and regular addition of organic amendments such as animal manures and crop residues can effectively offset many of these degradative processes. It also is the best way to develop a biologically active soil that requires less energy for producing crops, increases the resistance of plants to pests and diseases, and enhances the decomposition of toxic substances such as residual pesticides (Allison, 1973).

Indicators of Soil Quality

Efforts to characterize soil quality have focused primarily on soil chemical and physical properties because relatively simple and standardized methods of measurement are available. Soil biological properties have been neglected largely because of the difficulty in quantifying and predicting soil biological behavior, so that no single reliable index of soil quality has been developed.

Improved soil quality is generally indicated by increases in infiltration, macropores, aggregate size and stability, soil organic matter and aeration, and by decreased soil resistance to tillage and root penetration, and decreased runoff and erosion (Granatstein, 1990). More attention should be given to soil biological properties because their relationships with soil chemical and physical properties, plant health, and food quality are obviously important, but poorly understood. Plant health and nutritional quality may prove to be useful and reliable indicators of soil quality (Hornick, 1992).

Soil microorganisms and invertebrates play a vital role in decomposition of organic matter and nutrient cycling, and could be important indicators of soil quality. The various species, numbers, and functions of these organisms often are sensitive to environmental stresses and changes in soil properties associated with tillage and cropping practices. Changes in biodiversity of soil organisms (microorganisms, insects, and earth worms) may provide indications of soil degradation or rehabilitation (Stork and Eggleton, 1992; Visser and Parkinson, 1992).

Besides these properties, other potential indicators of soil quality should be considered, including crop yield (grain or biomass production), plant vigor, rooting patterns, and surface and groundwater quality. In certain situations, the latter may be very important since water quality can profoundly affect soil chemical, physical, and biological properties.

Although some indicators of soil quality may be sensitive to change, others may be more subtle. The overlying question is whether we can measure and quantify these indicators and develop them into a Soil Quality Index that can be used reliably to monitor and predict the effects of farming systems and management practices on soil productivity, environmental quality, food safety and quality, and human and animal health. Moreover, can these indexes provide an early indication of soil degradation and the need for remedial measures, and characterize changes in soil properties that would reflect the extent of rehabilitation or regeneration of degraded soils?

The ultimate goal is to develop a mathematical relationship or model that could quantify the various attributes of soil quality, and from it derive one or more indexes for simulation and prediction.

Such a relationship could take the following form:

Soil Quality Index = f(SP, P, E, H, ER, BD, FQ, MI)

where

SP = Soil Properties
P = Potential Productivity
E = Environmental Factors
H = Health (Human/Animal)
ER = Erodibility
BD = Biological Diversity
FQ = Food Quality/Safety
MI = Management Inputs

We would have to determine the interaction of these indicators, and the relative weight of each. Much valuable information is already available from research on benchmark soils and from long-term tillage and fertility trials.

We can also speculate on how soil quality indices might be used, including the following:

1. Assess the impact of management practices on soil degradation and soil conservation.
2. Assess the accrued benefits on highly erodible lands under the Conservation Reserve Program that was authorized by the 1985 Farm Bill.
3. Provide a basis for conservation compliance.
4. Establish the loan value and price of land.
5. Establish a more realistic base for tax assessment and tax credit.
6. Assess the impact of management practices on human and animal health.
7. Assess the impact of management practices on food safety and quality.
8. Assess the impact of management practices on water quality.
9. Provide information for simulating and predicting environmental change.
10. Provide an improved basis for land capability classification.

Monitoring and Assessing Global Soil Quality

There is an urgent need to develop the institutional capability for continuously monitoring and assessing the status or quality of the world's soil resources (Sanders, 1992). This should be linked with other efforts in the arena of global change, and include the development of databases and multinational programs on environmental issues such as air and water quality, soil biological diversity, and global warming. The soil is a highly interactive

component of regional and global processes that can significantly influence the behavior and response of agroecosystems.

An example is the issue of carbon dioxide buildup in the atmosphere and warming of the earth's environment. The soil can be either a net source or a net sink for carbon. The loss of carbon from surface soil layers from cultivation of arable lands was estimated at 30% over a 20- to 50-year interval (Schlesinger, 1986). The net release of carbon from agricultural clearing operations during the past decade was estimated at 15% of the annual emission from the burning of fossil fuels (Houghton et al., 1983; Schlesinger, 1984). However, Kern and Johnson (1991) have estimated that increasing the adoption of conservation tillage in the U.S. from 27 to 76% of planted cropland could change agricultural land from a net source of atmospheric carbon to a net carbon sink. Thus, soil quality and land use should be given high priority in observational and monitoring programs on global change.

A program on monitoring and assessing soil quality on a global scale would accomplish the following important objectives:

1. Create a global awareness and concern for the world's limited and fragile soil resource base and its relationship to environmental parameters that affect agroecosystems.
2. Stimulate local and regional concern about the widespread degradation of agricultural soils that is occurring from mismanagement and improper land use, and the threat this poses to the sustainability of agriculture and the quality of human life.
3. Enhance the quantification of soil quality indexes that are essential for identifying problem areas and for reliably estimating world food prospects.
4. Provide information that is needed to develop reliable models that can simulate and predict global environmental change.
5. Provide information to governments that is essential for drafting realistic agricultural policies and for allocating limited resources for programs to conserve, protect, and improve the soil resource base.

Current Initiatives to Expand our Knowledge of Soil Degradation and Soil Quality

We have only limited quantitative data on the rate and extent of soil degradation and its effects on soil quality and loss of productivity. Nevertheless, some countries and organizations have recognized the need for this information and have begun compiling national, regional, or global databases on soil degradation and soil quality. We briefly discuss some examples:

The United States: Several definitive studies have shown how erosion is related to loss of soil productivity (Papendick et al., 1985; Pierce et al., 1983). Many states have developed or are now developing guidelines and standards for certifying organically grown foods. One criterion sometimes used requires the producer to provide evidence that soil quality is being improved, or that it is being maintained at a high level.

Efforts are underway in some countries using computer models such as the U.S. Erosion Productivity Impact Calculator (EPIC) and the Productivity Index (PI) to evaluate the long-term productivity and economic impacts of soil erosion (Pierce et al., 1983). In some cases, computer-based expert systems are being developed to advise practitioners on remedies for soil degradation. So far, however, no program or procedure can track changes in soil quality on a global scale.

France: The Government of France established an observation network for soil quality in 1985 (Gomey and Juste, 1986). Priority was given to soil contamination by heavy metals, but other factors also are being monitored, including physical and chemical properties, plant products, biological properties, and physical degradation other than erosion.

African Soil Science Society: At their inaugural conference in 1988 in Kampala, Uganda, the African Soil Science Society Organizing Committee drafted a resolution calling attention to the problem of rampant soil degradation throughout the continent as the principal cause of declining food production and increasing poverty. The committee urged scientists to develop improved management practices that would halt soil degradation, restore productivity, and conserve the soil resource base for future generations.

International Federation of Organic Agriculture Movements: The alarming rate of soil degradation in Africa and the need to implement remedial and regenerative measures was also emphasized at the Seventh IFOAM Conference held in 1989 at Ouagadougou, Burkina Faso. This was the first time that IFOAM held its conference in a developing country. It brought U.S. and European scientists face-to-face with the monumental problem of restoring and improving the productivity of severely degraded agricultural lands and the overriding question of how this would be accomplished with such limited resources (Reganold and Parr, 1988).

Canada: In 1990, Agriculture Canada initiated a National Soil Quality Evaluation Program, with the objective of developing nationally acceptable criteria and standards of soil quality, and a periodic assessment of the status of soil quality and soil degradation. The program will identify and monitor the processes that cause changes in soil quality, and develop procedures and systems for predicting these changes. It also will provide a means for measuring changes in soil quality over time, to ensure that appropriate and effective land management practices are implemented. More than 20 benchmark sites have been established across Canada to monitor changes in soil properties under different farm management systems. The overall goal of the program is to develop the capability of evaluating the effect of changes in soil quality indicators on the productivity and sustainability of farming systems in Canada and elsewhere (M.A. Arshad, Agriculture Canada, personal communication).

United Nations: The United Nations Environment Programme (UNEP) and the International Soil Reference and Information Center (ISRIC) in Wageningen, The Netherlands, completed publication of a world map on human-induced soil degradation (Oldeman et al., 1990). More than 2,000 mapping units provide information on the type of degradation process (e.g., water erosion, wind erosion, and chemical or physical deterioration), and the soil's

status expressed as a combination of the degree of soil degradation and fraction of the mapping unit affected.

Relationship of Soil Quality to Alternative Agriculture and Sustainable Agriculture

The National Research Council (1989) defined alternative agriculture as a system of food and fiber production that applies management skills and information to reduce costs, improve efficiency, and maintain production levels through such practices and principles as:

- Crop rotations instead of monoculture
- Integrated crop/livestock systems
- Nitrogen fixing legumes
- Integrated pest management
- Conservation tillage
- Integrated nutrient management
- Recycling of on-farm wastes as soil conditioners and biofertilizers.

A U.S. House of Representatives Report (1988) considered low-input or alternative agricultural practices as promising strategies for preventing groundwater pollution and lowering farmers' production costs. The report implied that these goals could be achieved by reducing, or largely excluding, the use of chemical fertilizers and pesticides.

Sustainable agriculture is increasingly viewed as a long-term goal that seeks to overcome problems and constraints that confront the economic viability, environmental soundness, and social acceptance of agricultural production systems, both in the U.S. and worldwide. Although there are many definitions of sustainable agriculture, most of them encompass the same elements: productivity, profitability, conservation, health, safety, and the environment. They differ mainly in emphasis.

The U.S. Congress (1990), in drafting the Food, Agriculture, Conservation, and Trade Act of 1990, P.L. 101-624 (better known as the 1990 Farm Bill), defined sustainable agriculture as an integrated system of plant and animal production practices, having site-specific application, that over the long-term will do the following:

- Satisfy human food and fiber needs
- Enhance environmental quality and the natural resource base
- Make efficient use of nonrenewable resources
- Use natural biological cycles and controls
- Improve the economic viability of farming systems
- Enhance the quality of life for farmers and society as a whole.

As mentioned earlier, soil quality is now considered in a broader context to include attributes of food safety and quality, human and animal health, and environmental quality. It follows that the best means to improve or maintain soil quality are alternative agricultural practices such as crop rotations, recycling of crop residues and animal manures, reduced input of chemical fertilizers and pesticides, and increased use of cover crops and green manure crops, including nitrogen-fixing legumes. These help to maintain a high level of soil organic matter that enhances soil tilth, fertility, and productivity, while protecting the soil from erosion and nutrient runoff. Effective implementation of these alternative agricultural practices using a holistic or systems approach requires skilled management and innovativeness by the farmer.

A conceptual diagram of how the attributes of soil quality link the strategy of alternative agriculture to the ultimate goal of sustainable agriculture is shown in Figure 2. Soil quality occupies a pivotal position in this concept, and many would agree that soil quality is the "key" to agricultural sustainability.

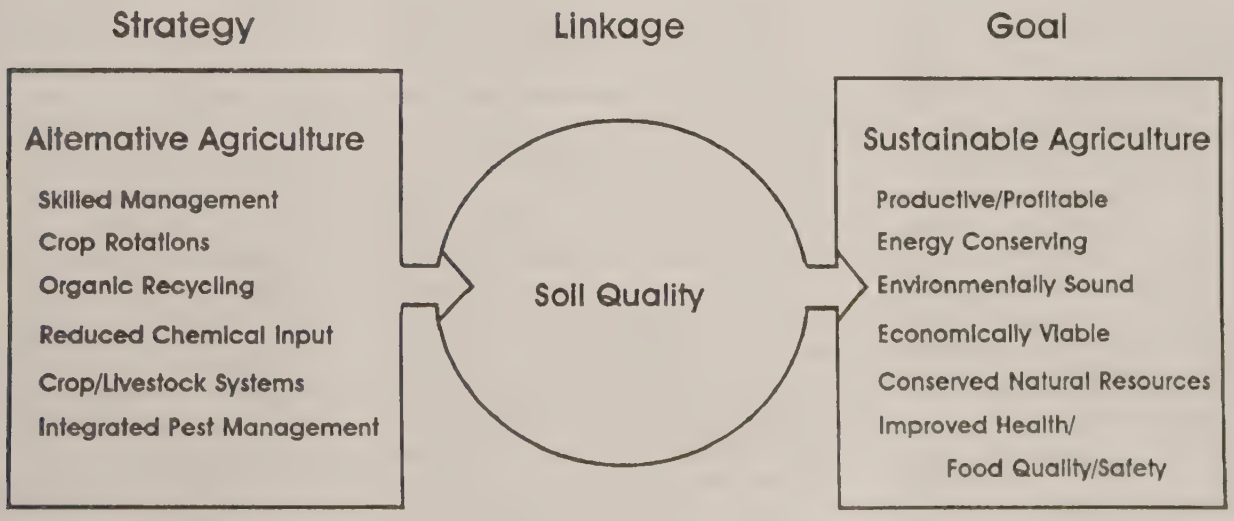

Figure 2. A conceptual diagram that illustrates how the attributes of soil quality provide a link between the strategy of alternative agriculture and ultimate goal of sustainable agriculture.

Research Needs and Priorities

There is a strong consensus that establishing a global network for monitoring, assessing, improving, and restoring the quality of degraded soils is a logical and appropriate goal. Research is needed to quantify the indicators or attributes of soil quality into indexes that can accurately and reliably characterize the relative state of soil quality as affected by management practices and environmental stresses. The best indicators of soil quality probably will differ according to agroecological zones, agroclimatic factors, and farming systems. For example, soil quality indicators would be different for paddy rice and for crops grown in well-drained soils.

Before a global network is developed, baseline information is needed. For example, literature surveys should be conducted to gain perspectives on monitoring requirements and the potential effects of changes in land use on soil quality. These surveys should include estimates of how much soil degradation costs farmers and society, and how various indicators of soil quality could be integrated to provide higher order indexes or attributes. From such information, maps could be produced to focus attention on the severity of degradation and conservation priorities. A logical first step may be to compile national and regional databases that could be linked into a global network.

We also need to improve our monitoring and assessment capabilities. For example, remote sensing and geographic information systems (GIS) could greatly enhance our ability to monitor changes in soil quality on a landscape basis. Existing land classification systems such as the Land Capability Classification System (Reganold, 1986) and the Storie Index Rating Scheme (Storie, 1976), need to be evaluated and possibly modified to provide accurate and meaningful characterizations of how land use affects soil quality.

Questions inevitably will arise regarding the feasibility of an effective global network for monitoring soil quality. Moreover, what is the best way of organizing and implementing such a program? What institutions or agencies should be involved? How should the program be managed? How is the information to be processed and used? And who is going to pay for it? Hopefully, most of these questions will be answered as linkages develop between institutions, projects, and soil quality researchers. Workshops, seminars, conferences, and task forces also will provide strong incentives to develop such a network.

In their paper on international networking of agricultural research, Plucknett and Smith (1984) discussed the essential elements on which successful networks are based. Perhaps most important, the problem should be defined clearly and a realistic research agenda developed. Then, the problem must be widely shared; strong self-interest by scientists and governments must be reflected; participants must be willing to commit personnel, facilities, and other resources; outside funding from interested donors must be available to operate the network for a reasonable time; participants must have the necessary training and expertise to make meaningful contributions; finally, it is essential to have strong and effective leadership. If any of these elements is missing, the prospects for a successful network are diminished. We should keep these principles firmly in mind as we pursue our goal of a global network for monitoring and assessing soil quality.

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SPECIAL REPORT

Farmer-to-farmer exchange between U.S. and Italy

Benjamin Stinner

From March 26 to April 2, 1992, longtime sustainable farmers from Ohio and Iowa traveled to northern Italy to meet with Italian farmers and other agriculturalists throughout Europe. The trip was sponsored by ESAV (Ente Sviluppo Agricolo Veneto, or Veneto Agricultural Development Board). This regional agency is responsible for research and extension programs and environmental policy in the region west of Venice (Veneto), representing a large portion of agricultural land in Italy. Major crops include corn, soybeans, sugar beets, and wheat. As in the United States, there is much concern in Italy over agriculturally-related non-point source water pollution, and most recently, over low commodity prices, especially with the GATT negotiations.

Ben and Deborah Stinner, professors at The Ohio State University College of Agriculture, at the invitation of ESAV and the University of Padua, spent April and part of May 1990 giving seminars and workshops in Veneto that featured their work with sustainable farmers and farmer mentorship programs. In June of that same year, representatives from Italy (Veneto Region), under the leadership of Maurizio Paoletti, traveled to Ohio and Iowa, where they visited the farms of the Sprays (Mount Vernon, Ohio), Thompsons (Boone, Iowa), Hartzlers (Smithville, Ohio), and Elstons (Grover Hill, Ohio). These same farmers now were able to travel to Italy for the workshops. Subsequently, a trip and week-long program was organized so that Italian farmers and agriculturalists throughout the Veneto Region could meet with these U.S. farmers. Traveling to Italy with the farmers were John Luna and Susan Rutherford, who are LISA (Long-Input Sustainable Agriculture) researchers from Virginia Polytechnic Institute, Kent Olsen from the University of Minnesota, and Deborah and Ben Stinner. The Italian organizers included Paoletti, Rosanna Favretto and ESAV personnel.

The trip was organized around meetings and workshops at Motta di Livenza, Verona and Rovigo, and farm visits in the Veneto Region. Presentations emphasized the importance of the family for family farms making the transition from conventional to sustainable practices, orientation toward long-term rather than short-term profits, yield stability, plant and livestock health, minimum and ridge tillage in combination with cover crops and rotations to sustain soil fertility and manage weed populations, and future research that combines farmers' experiences with the methods of science. On this last point, it was emphasized that northern Italy is a most appropriate venue for such discussions, because it has had such a long history of hosting people who are seeking new ways of combining knowledge.

Participating in this exchange were Adel Titti from Stuttgart, Germany, and Frank Wijnands of Lelystad, The Netherlands, both researchers on sustainable farming systems. They contrasted their experience in Europe to the U.S., where they observed that in the U.S. more of the innovation in sustainable agriculture is driven by individual farm families or farmer-based groups such as the Practical Farmers of Iowa. In Europe, these researchers see more of the innovation coming from university groups with subsequent transfer to the farming community. Also, represented was the Organization for Economic Cooperative Development.

Representatives from Central Europe, including Poland, Hungary, Czechloslavakia and Croatia, stressed that as their countries rebuild agricultural and local economics, they very much want to go in the direction of sustainable agriculture with farmer-oriented research and education programs.

The week was a rich experience made possible by the Italian generosity. The participants look forward to future collaboration.

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The need for a soil quality index: Local and regional perspectives

D. Granatstein and D.F. Bezdicek

Abstract. *Our knowledge of soil is based primarily on quantitative analysis of isolated physical, chemical, and biological properties. However, the interaction of these quantitative aspects determines soil quality. Integrative tools are needed by researchers, farmers, regulators, and others to evaluate changes in soil quality from human activity at a local and global level. An index needs to be adaptable to local or regional conditions. For example, the parameters needed to determine changes in soil quality may differ between a semi-arid wheat field and a rice paddy. Suitable reference points and optimum ranges are needed for soil quality attributes. The present challenge is to integrate a suite of soil tests into a meaningful index that correlates with productivity, environmental, and health goals.*

Key words: soil health, soil condition, soil analysis

Introduction

Interest in soil quality dates back to ancient agriculturalists. Varro, a Roman scholar, noticed about certain crops that "when cut down and left they improve the soil." More recently, concern over the health of soil was articulated by Albert Howard (1947) and the Rodales (Rodale, 1981). Today the term soil quality is used with increasing frequency in both the popular and scientific press, suggesting a broadening awareness about the critical importance of the soil resource and the need to monitor it more closely.

Current scientific knowledge of soil is based on analysis of various soil components. This approach often reveals little about the complex interactions of biological, chemical, and physical components that make soil a unique medium. The interest in a soil quality index represents an attempt to address this problem. Yet there is a contradiction in any attempt to quantify soil quality because of its qualitative nature. Some farmers use sensory indicators such as smell, feel, and ease of tillage to judge soil quality and the health of their fields (Beus et al., 1990), but these indicators are hard to quantify. A soil quality index needs to be sensitive to both sensory and quantitative aspects.

Four strategies can be followed in studying soil quality: quantitative analysis of soil for specific attributes (e.g., carbon and nitrogen content); study of undisturbed soil in the field (e.g., earthworms, water infiltration); bioassay with plants or animals (e.g., yield, animal weight gain); and monitoring of ecosystem processes (e.g., watershed dynamics, nutrient balances). These strategies vary from the most reductionist to the most integrative. Watershed level assessments integrate most of the important soil quality attributes, but are expensive to conduct and require evaluation over a long time.

It is unlikely that any single index will serve all cropping systems or geographic areas. A uniform process is needed for selecting specific soil quality criteria for an individual situation. At the Rodale Institute Conference on the Assessment and Monitoring of Soil Quality (Rodale Institute, 1991), three basic components of a soil quality index were proposed to help standardize soil measurements across diverse environments: 1) the ability of soil to enhance crop production (Productivity component); 2) the ability of soil to function in attenuation of environmental contaminants, pathogens, and offsite damage (Environmental component); and 3) the linkage between soil quality and plant, animal and human health (Health component). The purpose of this paper is to describe the need and potential uses for a soil quality index and to identify barriers to be overcome in developing a valid index.

The Need for a Soil Quality Index

Numerous quantitative properties are potential indicators of changes in soil quality (Wilde, 1955; Chapman and Pratt, 1961; Black, ed., 1965; Page, ed., 1982; Smith and Mullins, eds., 1991). These include microbial biomass, diversity, and activity; carbon and nitrogen content and dynamics; fertility status and nutrient availability; soil structure; and water infiltration. Studies of changes in soil characteristics under experimental treatments or contrasting long-term management typically generate large data sets from a suite of measured parameters. But it often is difficult to judge quantitatively whether the soil as a whole has improved, deteriorated, or stayed the same, since integration of the analytical results remains subjective.

For example, soil properties of a conventionally farmed field in eastern Washington were compared to those of a field on an adjacent low-input farm after 40 years of divergent management (Table 1). Soil from the low-input farm had significantly higher enzyme levels, microbial biomass, and soil organic matter (Bolton et al., 1985). It had significantly higher available

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phosphorus levels (Patten, 1982), and suffered significantly less erosion (Reganold, 1988). The low-input soils also had a higher ability to adsorb pesticides (Mallawatantri and Mulla, 1992). Average wheat yields on the low-input farm were 8% lower than on the conventional farm, but they were similar to yields on another neighboring conventional farm.

The cumulative properties measured in these studies likely reflect changes in soil quality, although it is difficult to assess the contributions from individual practices. Although there is scientific and popular consensus that the reduced soil erosion and increased pesticide adsorption on the low-input farm represent positive changes in soil quality, there is less agreement about the meaning of higher microbial biomass or enzyme levels. Thus, relationships need to be established between individual assays and the three soil quality components mentioned above so that judgments can be made about soil quality improvement or deterioration. Ultimately, any measure of soil quality will need to be linked to value judgments based on human-centered goals such as ample food production, improved water quality, and improved human health.

Crop yield can be an important indicator of soil quality, because it serves as a plant bioassay of the interacting soil characteristics. However, productivity alone is not a complete measure of soil quality. For example, in the Palouse region of eastern Washington, extensive soil erosion has occurred during the past century, yet average winter wheat yields have increased linearly (Soil Conservation Service, 1979). Using crop yield and soil loss as two possible indicators of soil quality would lead to conflicting conclusions about how the condition of Palouse soils has changed. Measures such as stability of yield over time or the resilience of yield to perturbations or stress are preferable to absolute productivity (Conway, 1985). Other important considerations are the efficiency of production (output per unit of input) and potential environmental impacts. Bushels of grain produced per ton of soil lost, or yield per unit of fossil fuel input can tell us more about soil quality than yield per acre or per hour of labor. The last two yield measurements address only the productivity aspect of soil quality, and ignore the environmental and health components.

Table 1. Comparison of soil characteristics between adjacent fields with contrasting historical management (adapted from Reganold, 1988).

	Low-input Farm[1]	Conventional Farm
Average wheat yields (Mg ha^{-1})	4.53	4.92
Polysaccharides (g kg^{-1})	1.13	1.00
Organic matter (%)	2.5	2.00
Depth to clay horizon (cm)	55.6	39.9
Estimated average soil erosion (Mg ha^{-1} yr^{-1})	7.9	20.4

[1]This farm used no commercial fertilizer and used crop rotations that included green manures.

Table 2. Effects of crop rotation on soil carbon and aggregation, Ohio. Values measured in August. (Adapted from Willard, 1959).

Rotation	Soil Carbon (%)	Water Stable Aggregates >0.25 mm (%)
Corn	1.51	26
Corn + 100 lb N per acre	1.63	28
Corn-soybeans	1.33	32
Corn-soybeans-wheat + clover	1.33	39
Corn-soybeans-wheat-hay	1.26	32
Corn-wheat-hay-hay	1.51	54

Soil organic carbon (or organic matter) is probably the most universal gross indicator of soil quality presently available (Rasmussen and Collins, 1991). Both farmers and researchers generally consider an increase in organic carbon to be a positive change in soil quality. But significant biological, chemical, and physical differences can exist between two soils with the same organic matter content. Australian researchers found very similar organic carbon contents in soils from plots under continuous pasture and virgin vegetation, but the virgin soils had over 70% more water stable aggregates (> 2 mm) than the pasture soils (Russell and Williams, 1982). Canadian researchers (Perfect and Kay, 1990) and Ohio crop rotation studies (Table 2) also have shown that organic carbon and water stable aggregation are not necessarily correlated. Since changes in soil attributes such as organic matter can vary significantly with depth, soil quality comparisons between practices (e.g., no-till versus conventional tillage) must balance results from surface soil with those from the tillage zone and the rooting zone. A valid soil quality index would help interpret data from batteries of soil measurements and show whether management and land use are having the desired results for productivity, environmental protection, and health.

Uses of a Soil Quality Index

Farmers, researchers and policymakers are interested in an integrative soil quality index to monitor changes in soil over time. Many farmers are concerned about the long-term effects of contemporary farming practices on the soil resource (Beus et al., 1990). They are evaluating new products and practices through on-farm testing, but they lack a good indicator of changes in the soil system. Farmers who use alternative cropping practices such as green manures often report improvements in soil tilth and reduced disease problems. A growing number of products and management

recommendations carry claims regarding soil health or improved soil life that are difficult to verify or refute within our current soil analysis framework. Farmers need a soil quality index that can help them evaluate the economic potential of new options and their impact on the soil resource.

In the U.S., the 1985 Farm Bill mandated soil and water conservation compliance for commodity program participants. In developing conservation plans with farmers, the Soil Conservation Service (SCS) has relied heavily on predictive soil loss equations and easily measurable parameters, such as surface crop residue and tillage practices. Some farmers who use alternative practices such as green manure believe that their farming systems have improved soil quality and thus reduced erosion potential compared to other farming systems on the same soil type. They question the need for additional practices such as minimum tillage or strip-cropping on their farms.

A soil quality index might help the SCS resolve this issue. In the 1960s, the SCS developed a Soil Conditioning Rating Index (Soil Conservation Service, 1974) to evaluate the effect of entire cropping systems and rotations on soil quality, but it was not widely used. Researchers have shown that the K factor (soil erodibility) assigned to a given soil series can be changed substantially by management (Table 3) and perhaps should not be considered a constant in using the Universal Soil Loss Equation (Gersmehl et al., 1989). An index also would help the SCS evaluate the impact of the Conservation Reserve Program and suggest future policies to maximize benefits from the 10-year public investment.

Researchers and policymakers would find a soil quality index useful in evaluating policy decisions and measuring progress. For example, considerable public and private resources have been committed nationally to the development of no-till technology. Many tests currently used to evaluate soil indicate that no-till enhances quality (Doran, 1980; Dormaar and Lindwall, 1989). Yet a study in Ohio found the water infiltration rate of a soil from a diversified Amish farm to be seven times greater than that on a soil from a no-till maize farm (Jackson, 1988). Although no-till offers significant soil conservation benefits compared to many conventional tillage systems, a soil quality index would help to identify other promising approaches in need of further research and extension.

Table 3. Change in K factor (soil erodibility) of the Universal Soil Loss Equation for a Seaton silt loam soil due to past use, Wisconsin (adapted from Gersmehl et al., 1989).

Past Use	Silt (%)	Organic Matter (%)	K
Virgin forest	83	3.8	0.27
Crop rotation	86	1.5	0.39
Continuous maize	89	0.7	0.51

Table 4. Soil quality reference points.

Farming System	Native Ecosystem	Reference Point
Dryland wheat (Montana)	Prairie	Prairie
Rainfed maize (Wisconsin)	Temperate forest	Grass sod ?
Paddy rice (Philippines)	Tropical rainforest	?
Irrigated cotton (Arizona)	Desert	?

A soil quality index would improve economic assessments of agriculture. It would help assign full economic and environmental values to practices such as cover crops, conservation tillage, or green manures. Farmers could be more convincing to lenders and landlords about the need for such practices in cases where they are beneficial. Also, an index would help assign a more accurate value to agricultural land based on resource efficiency and environmental considerations such as erosion and agrichemical leaching, not just on proven yield.

Environmental and regulatory agencies need an indicator to determine whether degraded soils have been restored satisfactorily in locations such as strip mines or Superfund sites. Soil plays a role in global change that is not fully understood, acting as a source/sink for greenhouse gases (Johnson and Kern, 1991). A soil quality index would help monitor progress for these concerns.

If relationships between soil quality and human health are established, consumers might use a soil quality index in making food decisions. This could become an important market force to influence farming practices.

Reference Points for Soil Quality

Human activity has altered many ecosystems and the condition of soils around the globe. Some changes have improved the soil for agricultural use, but other changes have impaired the soil's ability to provide for human needs. A soil quality index needs reference points that reflect both the general potential for human use and the unique biophysical conditions of a specific location. What should be considered the standard: the native soil conditions at a site, or the conditions that maximize agronomic, environmental, and economic performance? What is more useful: absolute measures, or measures of relative change over time?

The prairie ecosystem of the Great Plains provides a logical reference point for interpreting changes in soil quality under semiarid cereal cropping. The original plant community was dominated by native perennial grasses. With the introduction of agriculture, these species were replaced with annual cereal grasses, such as maize, wheat, barley, and oats. Soils formed under the native vegetation usually are high in organic matter, tilth, and other attributes considered optimum for

Table 5. Human-induced transformation of an Amazonian oxisol (Terra Preta) in Brazil, 3 cm depth (adapted from Zech et al., 1990).

	Clay (%)	pH ($CaCl_2$)	Organic C (g kg^{-1})	Exchangeable Ca (cmol kg^{-1})
Native soil	83	3.7	30	tr.
Terra Preta	63	6.3	92	39

Table 6. Potential indicators of improved soil quality.

Improved soil quality indicated by *increasing*:	
infiltration	water holding capacity
macropores	aggregate stability
aeration	soil organic matter
biological activity	

Improved soil quality indicated by *decreasing*:	
bulk density	soil resistance
runoff	diseases
erosion	production costs
nutrient losses	

the cultivated crops. In this case, the native soil provides a good reference point for soil quality. Many long-term studies have used the native soil as a benchmark for comparison with differing management systems (Skidmore et al., 1975; Rasmussen et al., 1989). Native sites, cemeteries, and farm fields with contrasting long-term management all offer potential reference points for soil quality in areas where long-term research plots are not present. Often soil conditions under long-term grass sod are used as a reference point in ecosystems that were not originally grassland. Since grassland soils provide good growing conditions for many crops, this may be a reasonable approach for temperate regions.

For many agroecosystems, the reference point is not so obvious (Table 4). Soils have been changed by management to provide more suitable conditions for crop plants, and thus soil quality for agricultural purposes often has been improved. A striking example is the development of Terra Preta soils in the Amazonian basin of Brazil, where human activity led to a dramatic change in the make-up of an Oxisol (Table 5). The proper reference point is equally obscure on paddy rice soils that were not originally flooded or on desert soils that are now irrigated. Wastewater applications to desert soils can significantly increase soil organic matter while also increasing heavy metal content and salinity. A determination of net soil quality change becomes difficult in such situations.

A soil quality index must be sensitive to how the soil is used. Table 6 lists several changes in soil that are widely regarded as improvements in soil quality. Although increased infiltration and aeration and decreased bulk density may enhance maize and wheat production, they are not desirable for paddy rice soils. A field with soil conditions favorable for alfalfa will probably not be suitable for blueberries. Thus, soil quality assessments may need to vary with the intended crop.

In evaluating soil quality, it is possible to have too much of a good thing, such as organic matter or a single nutrient. Optimum ranges for soil quality parameters need to be identified for different climates and uses. Increased soil organic matter levels are generally considered a positive change in soil quality. But an increase in organic matter beyond the optimum for a crop would represent a decrease in soil quality.

The Future

Researchers presently select a small subset of possible analytical tests for assessing soil quality. New assays are continually developed, including those that use sophisticated technologies such as nuclear magnetic resonance, super-critical fluid extraction, and DNA probes. A major challenge in developing a soil quality index is to establish guidelines for selecting assays that reflect changes in specific agroecosystems and the productivity, environmental, and health components of soil quality. The process must integrate quantitative, reductionist results into a cost-effective and meaningful index.

Soil physical tests need to include some *in situ* measurements, such as infiltration, that reflect the soil condition in place without disturbance. These tests should account for macroscale variation such as distribution of earthworm tunnels or root channels, topography, and restrictive layers that are not easily determined from laboratory tests. Soil chemical tests are probably the most consistent and repeatable. Tests such as total N or pH are less influenced by short-term factors than many of the physical tests. Ratios of results from two or more tests may provide better integration and meaning than results from individual tests.

The microbial life of the soil is often considered as a key element of soil "health" or quality (Howard, 1947; Higa, 1991). Results from microbial assays are often difficult to interpret. Methods to evaluate microbial diversity are not adequately defined, although new tools such as RAPS (random amplification of polymorphic DNA) allow further study of diversity, which may be more important to soil quality than population or activity. Microbial tests need to be correlated with key physical and chemical factors for soil quality testing.

Plant or animal bioassays provide an integrated analytical approach, but the proper parameters to measure in the plant or animal need to be determined. As mentioned earlier, several kinds of yield measurements can be made to give different information about a system. A quantitative measure of plant or animal health must be defined if these concepts are to be used as

indicators of soil health. Novel testing approaches such as radionics and circular chromatography (Pfeiffer, 1984) also need to be evaluated.

Concerns about food and fiber supplies, environmental protection, and human health are broadening our interest in the soil resource. In response, the volume of research data on soil components continues to grow. A soil quality index can provide a tool to integrate these component data into practical management guidelines and wise land use policies.

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Federal Court Orders Pesticide Ban

The U.S. Court of Appeals in San Francisco has ruled that the EPA must remove from the market any pesticides that have the potential to cause cancer and leave residues in processed food. The overruling of an EPA regulation, which kept the pesticides in use as long as they were deemed to have a trivial cancer risk, could ban at least 60 pesticides that show up in trace amounts in such processed food as jams, juices, and sauces. Environmental groups had argued that even "negligible" pesticide residues in processed foods can be banned under the Delaney Clause, which prohibits even trace amounts of carcinogens in processed foods.

Two States Take Steps Toward Sustainable Agriculture

In separate moves taken recently, Washington State has adopted organic meat and dairy standards, and California has formed a committee to help find alternative crop protection strategies to reduce the environmental problems associated with pesticide use.

Washington's standards specify the living conditions, disease prevention and control practices, and record-keeping requirements for organic meat and dairy production. Producers who meet these standards can market their products to consumers interested in buying meat and dairy products which have been produced without the use of antibiotics or hormones and in a manner not detrimental to the environment.

The California committee's goal is to encourage the development, testing, and dissemination of new pest management practices, with particular emphasis on the importance of the alternatives to pesticide uses that are critical to IPM. It will also help identify obstacles to IPM in California's regulatory system and in the U.S. Environmental Protection Agency.

International activities in assessing and monitoring soil degradation

D.W. Sanders

Abstract. *The problem of land degradation is not new, but never before has it been so widespread or affected the lives of so many people. The need for a global assessment of land degradation was highlighted by the United Nations Conference on the Human Environment in 1972. Since then, several attempts have been made to develop methodologies that will allow for systematic assessment and monitoring of global land degradation. Systematic work started in 1975, when FAO and United Nations Environment Programme (UNEP) collaborated in a study to develop a provisional method for soil degradation. This method was tested, and maps on a scale of 1:5,000,000 were produced for North Africa and the Near East. However, the method proved difficult to apply accurately, so this project was followed by another where the method was revised and refined in an effort to assess and map desertification. Again, problems were encountered because of the complexity of the subject and the lack of usable reliable data. More recently, ISRIC, using a simplified methodology and the assistance of some 250 scientists from around the world, has produced a world map of human induced soil degradation at a scale of approximately 1:10,000,000. Meanwhile, interest has been growing in the problem of nutrient depletion in developing countries and a study has been completed of N, P and K balances in the soils of 38 African countries. Although we still do not have an accurate assessment of global land degradation and no systematic monitoring is yet in place, these innovative studies have provided us with a sound basis for future work and have identified many of the practical problems of measuring land degradation, data collection and analysis that will have to be overcome before more accurate assessment and monitoring can be achieved.*

Key words: soil quality, soil erosion, nutrient depletion, desertification

Introduction

Today soil degradation is the subject of global concern. Humanity's very existence depends on the ability of a limited area of land to provide most of its food and much of its fuel and fiber requirements.

In spite of this importance, huge areas of land are today being degraded through improper use and poor management. So serious has the problem become that in some areas yields are dropping, and communities that once were self-reliant no longer can feed themselves. For example, the famines in Ethiopia of the 1970s and 1980s have been at least partly due to the effects of land degradation caused by years of intensive agriculture and soil erosion (Sanders, 1987).

The problem is not new. Ever since people first settled on the land and started cultivating it some 7,000 years ago, there have been problems of land degradation; over the centuries, great civilizations have risen and fallen in such places as Mesopotamia, China, North Africa, Egypt, Greece and Italy. Land degradation has been associated with the decline of all these great civilizations (Lowdermilk, 1953).

Although land degradation has been serious in the past, it was confined to relatively small areas or just a few countries at a time, and there was always new land to move to and develop. In this century, land degradation is different and more serious mainly because of its extent. Huge areas of Asia, the Near East, Australia and Latin America now are suffering from wind erosion, water erosion, salinization, waterlogging, soil toxicity and nutrient depletion, while the situation in Africa is so bad that a new word has come into use to describe the condition **desertification**; the creation of manmade deserts. Moreover, there is little good, new land left to develop; we are running out of land resources.

Land degradation is not only a problem of the developing world and the poor. It also is very serious in many of the more developed and technically advanced countries. For example, in spite of applying extensive soil conservation measures for over fifty years, it is claimed that the USA may still be losing as much as 6 billion tons of soil a year through erosion (Napier, 1986). A recent report by the Australian Government claimed that Australia was losing 90 million tons of soil annually, and that the "average cost to every Australian farmer of land degradation was [Australian] $3,600 a year" (Department of Primary Industries and Energy, 1989). These probably are only rough estimates, but they show the extent of the problem in these countries.

Although not well documented, erosion is becoming an increasing problem in Europe. There even are reports of increased erosion in England and Wales,

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with some 5% of the monitored land affected, even through they have mild, temperate climates (Evans et. al., 1988).

Although it is generally recognized that land degradation in general, and soil erosion in particular, are widespread and serious, little reliable information is available on its extent or degree. Part of the problem is that much of the available data are reported in different ways and not in readily comparable forms. For example, FAO reported in 1981 that worldwide, between 5 and 7 million hectares were being lost to agricultural production every year through different forms of land degradation. FAO also found that in Africa, north of the Equator, more than 35% of the land is affected by either erosion or salinization, while some 60% of the Near East is affected in the same way (Food and Agriculture Organization, 1981). A more recent FAO study indicates that Zimbabwe could be losing, on an average, as much as 1.6 million tons of nitrogen and 0.24 million tons of phosphorus per year through erosion (Stocking, 1986).

The World Resources Institute (1986) was not able to provide simple statistics on the global extent of soil erosion, but demonstrated its importance with many examples from different countries and regions: in Guatemala, 40% of the productive capacity of the land has been lost because of erosion and several areas have been abandoned because agriculture has become uneconomic; in Turkey, planners estimate that 75% of the land is affected, with 54% severely or very severely eroded; cleared areas of Nepal lose between 35 and 75 metric tons of soil per hectare per year; in India 13 million hectares are eroded by wind and nearly 74 million by water; since 1957, China alone has lost about 11% of its arable land because of erosion, desertification, and conversion to nonagricultural uses, and other causes (World Resources Institute, 1986).

These and many other data are available which, if pieced together, give a general picture of land degradation globally. However, all data must be looked at carefully in any analysis, because very different things often are recorded, and then incorrectly presented together. For instance, there are three different broad aspects to the problem of assessing land degradation: the *risk* of it occurring; the *rate* at which it is occurring; and how bad it is now, or its present *status*. These three aspects of degradation are frequently confused, and it is not uncommon to find reports in which two, and sometimes the three, are mixed. Other factors, such as the effects of natural or geological erosion, as opposed to accelerated or human induced erosion, also have to be carefully considered. Added to all of this is the fact that most forms of land degradation, even spectacular water erosion, are difficult to measure and map accurately.

In spite of these problems, several attempts have been made to assess and map the extent of global land degradation.

Global Assessments

Provisional method for soil degradation assessment

The need for a systematic global assessment of land degradation was highlighted as far back as the United Nations Conference on the Human Environment, held in Stockholm in 1972. As a follow-up to the recommendations of that conference, FAO and the United Nations Environment Programme (UNEP) held an Expert Consultation in Rome in 1974. The meeting recommended that a global assessment should be made of "actual and potential soil degradation," and, rather ambitiously, that "this assessment should be based on the compilation of existing data and the interpretation of environmental factors influencing the extent and intensity of soil degradation such as climate, vegetation, soil characteristics, soil management, topography and type of land utilization; the results of this assessment should be compiled as a World Map of Soil Degradation" (Food and Agriculture Organization, 1979).

As a result, FAO, UNEP and UNESCO collaborated to start a project in 1975 called "A World Assessment of Soil Degradation." Briefly, the objectives were to develop a methodology for assessing actual and potential land degradation, preparing guidelines for comprehensive data collection and catalyzing action on this subject.

Over the next three years a provisional method was developed for the assessment and mapping of land degradation. With this method, six groups of soil degradation processes were recognized: water erosion, wind erosion, excess of salts, chemical degradation, physical degradation and biological degradation. Data were to come from direct ground observation, remote sensing observations, and "observation on factors affecting degradation and on the damaging effects of degradation."

This method allowed two types of assessments to be made:

1. What was termed present degradation. This was the degradation that was actually occurring, expressed as **an annual rate**. (Problems arose because this had to be related to the **status** of degradation to obtain an idea of how much degradation at this rate the soil could withstand.)
2. The degradation risk. This was simpler, of course. It depends on such factors as the erosivity of the climate, the erodibility of the soils, and the condition of vegetation. It was reasoned that from the risk assessment it would be possible to predict future degradation under various land use systems and management factors.

Using this method, two trial areas were mapped at a scale of 1:5,000,000: Africa north of the Equator, and the Near East. Two maps were produced for each area; one showing "soil degradation risks" and the other "present degradation rate and present state of soil." These were published in 1979.

Unfortunately the results were not very satisfactory. In practice, the method proved to be complex and difficult to use, and the attempt to assess and map rate and present state of land degradation, two very different things, produced a map that was confusing to interpret. Also, the accuracy of some results was questionable. However, this first attempt at systematically assessing and mapping land degradation provided a very useful starting point for later efforts.

Provisional method for assessment and mapping of desertification

In 1977 the United Nations Conference on Desertification (UNCED) proposed an Action Plan to arrest and control desertification. In implementing this plan, UNEP collaborated with FAO in a project running from 1980 to 1984 that aimed at developing a methodology for the assessment and mapping of desertification. It was hoped that this would lead to the mapping of present desertification and allow desertification to be monitored. As desertification is, for the most part, land degradation, this project based its methodology on the earlier FAO/UNEP soil degradation methodology (Food and Agriculture Organization, 1984). However, it varied in two respects. First, instead of being based on six soil degradation processes, it used seven "desertification processes." These were:

1. degradation of the vegetative cover;
2. water erosion;
3. wind erosion;
4. salinization;
5. reduction in soil organic matter;
6. soil crusting and compaction; and
7. accumulation of substances toxic to plants or animals.

The first four were considered major determinative processes and the last three subordinate.

Second, instead of mapping the rate and status together, and risk separately, an attempt was made to assess and map four different aspects. There were:

1. the status (the situation as it is now, compared to a previous situation);
2. the rate at which desertification is taking place;
3. the inherent risk of desertification; and
4. the hazard of desertification (a rating established for mapping after combined consideration of status, rate and inherent risk of desertification).

After development, the provisional methodology was tested in Mexico, Texas, Upper Volta (now Burkina Faso), Sudan, Tunisia, Syria, Pakistan, Turkmen (USSR), and Australia. Some 35 specialists participated in the field testing and preparation of subsequent reports.

The provisional method was found to have several positive points: it was flexible, it could be used for mapping at different scales, it allowed the different "desertification processes" to be expressed as percentages and, unlike the earlier methodology, it overcame a fundamental problem by separating the two factors of rate and status.

On the other hand, it proved to have many problems and to be extremely cumbersome to use. Its main problem appears to be that to be applied properly, a great amount of detailed data is needed that seldom, if ever, are readily available over large areas. For example, in the Texas study the only good, readily available data were soil survey information. No maps of any kind were available to show current vegetation cover, or where severe gully or wind erosion existed. Also, data on livestock were aggregated in a form that was extremely difficult to use. Teams of specialists were needed, and it was impossible to show much detail (e.g., only areas greater than 10,000 ha at a scale of 1:2,000,000).

Because of these problems, the provisional methodology was not developed further. Again, however, it provided useful experience, and it has taken us another step toward the development of a practical method of assessing, mapping and monitoring land degradation.

The world map of the status of human-induced soil degradation

The most important recent work on assessing and monitoring land degradation has been done by the International Soil Reference and Information Centre (ISRIC). In 1982, the Governing Council of UNEP adopted a World Soils Policy, a document that aimed at "conserving this most important of natural resources and using it on a sustainable basis" (UNEP, 1982). An objective of the World Soils Policy is the development of methods to monitor global soil and land resources. If this is to be done, methods are required that can reliably detect significant changes in those soil and terrain characteristics that directly or indirectly affect the quantity and quality of the land and its ability to produce food, fiber and timber (ISRIC, 1990).

This and the growing use of computerized land data bases led to a proposal by the International Soil Science Society (ISSS) in 1986 to develop a World Soils and Terrain Digital Database, or SOTER as it has become known, at a scale of 1:1,000,000. UNEP has recognized the potential of SOTER to provide the scientific ingredients, soil and terrain attributes, for quantitative assessments of the rate and risk of soil degradation, in sufficient detail to use at the national or regional level. The problem is that it will probably take at least 15 years before we have world coverage through SOTER. UNEP has been under pressure to provide a global assessment soon so it decided to undertake two shorter-term tasks:

- a global assessment of soil degradation at a scale of 1:10,000,000, to be completed in three years; and
- a soil and terrain digital database and generation of soil degradation maps at a scale of 1:1,000,000 for five test areas in the framework of SOTER.

Global assessment of soil degradation

Because of this decision, UNEP entered an agreement with ISRIC in 1987, the Global Assessment of Soil Degradation (GLASOD), to do the following:

- produce a world map of human induced soil degradation at a scale of 1:10,000,000; and
- carry out a detailed assessment of the status and risk of human induced soil degradation for one field area in Latin America, covering parts of Argentina, Brazil and Uruguay, accompanied by a 1:1,000,000 map.

The project lasted 28 months. In carrying it out, ISRIC was assisted by many organizations, including the ISSS, the Winand Staring Centre of the Netherlands, FAO and the International Institute for Aerospace Surveys and Earth Sciences (ITC) of the Netherlands. Altogether this impressive piece of work involved some 250 scientists from all regions of the world.

In October, 1990, the project produced the first "World Map of the Status of Human Induced Soil Degradation" in three sheets at a scale of approximately 1:10,000,000, and an accompanying publication that explains the methodology used (ISRIC, 1990).

Development of the GLASOD map legend

The GLASOD map legend was developed with the aim of showing the seriousness of land degradation to policymakers and to the public at large. At the same time, every effort was made to show as much as possible of the detailed aspects of degradation as supplied by the regional coordinators.

Details of the legend are shown in Fig. 1. Four main "degradation types" were mapped:

- water erosion;
- wind erosion;
- chemical deterioration;
- physical deterioration.

Provision was also made for "stable terrain" and "nonused wasteland." The degradation types were linked with five "causative factors":

- deforestation and removal of the natural vegetation;
- overgrazing;
- agricultural activities;
- exploitation of vegetation for domestic use;
- (bio)industrial activities.

The results were combined to give each mapping unit a soil degradation status. To this was added an indication of the rate of degradation in the recent past (5 to 10 years).

Once completed, the method was passed on to regional correlators who made the best use of whatever data and experience were locally available to map the various regions. The results were then collated, digitized and mapped.

The result was the first global map of land degradation that had acceptable accuracy and detail. Some details of the mapped units have been questioned; no doubt, refinements and corrections will be needed. Nevertheless, the GLASOD has been an innovative and remarkably successful exercise and has provided us with a simple, practical methodology to develop further. A feature of this methodology is that it allowed the best use to be made of any available data. It also made use of the personal experience and judgement of local experts in all regions.

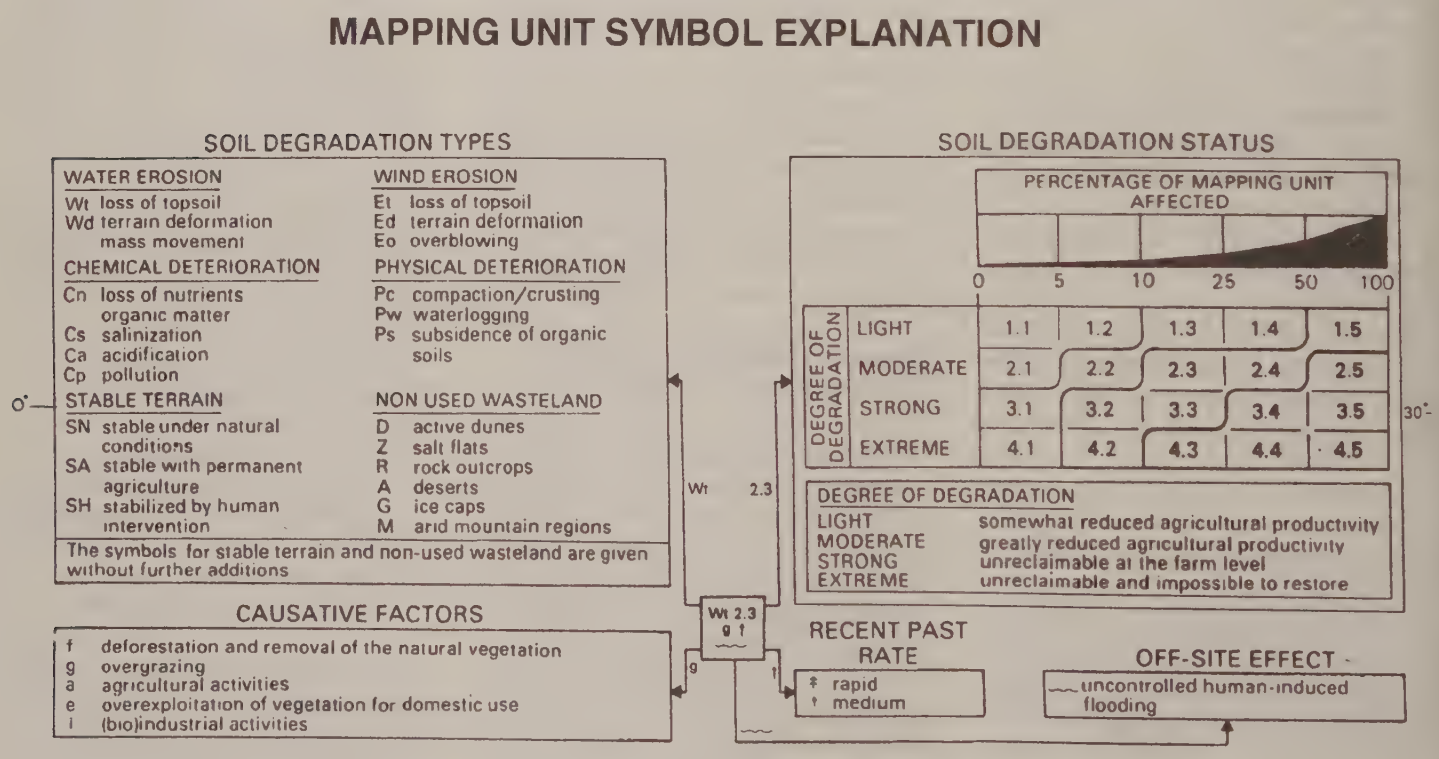

Figure 1. Mapping unit symbol explanation.

Assessment of nutrient depletion

Until recently, most attempts to assess and map land degradation have concentrated on the physical aspects, such as soil loss through wind and water erosion, and on the accumulation of toxic substances. Little thought appears to have been given to an equally important form of land degradation, nutrient depletion. A recent study undertaken by Winand Staring Centre of the Netherlands for FAO (Stoorvogel and Smaling, 1990) therefore has provided a valuable insight into this subject.

This study covered 38 sub-Saharan African countries, and was based on the net removal of the macronutrients N, P and K from the rootable soil layer. The study used FAO production figures for 1983, and projected production figures for 2000, by crop and country. These figures were broken down into six "Land/Water Classes," based mainly on climate: low, uncertain, and good rainfall areas, problem areas, naturally flooded, and irrigated areas. Data from 1983 and projections for 2000 were used to estimate fertilizer use by country and crop. Next, factors controlling the nutrient flow into and out of the soil were defined and quantified for each Land/Water class. From this, Land Use Systems were defined, each of which was assumed to be homogeneous; these were the unit for the calculations of the nutrient balance.

It was then reasoned that the fertility dynamics of each Land Use System were governed by five input (IN) and five output (OUT) factors.

The input factors used were:

- IN 1: Mineral fertilizers;
- IN 2: Manure: both on the spot manuring by animals and manure collected from kraals and spread;
- IN 3: Deposition by dust and rain;
- IN 4: N fixation;
- IN 5: Sedimentation: applied only to the naturally flooded or irrigated areas.

The output factors were:

- OUT 1: Harvested product: average figures for each crop;
- OUT 2: Crop residues: this included allowance for the removal of some residues;
- OUT 3: Leaching: only applied to N and K;
- OUT 4: Gaseous losses: based on denitrification and volatilization;
- OUT 5: Erosion: Estimated soil loss multiplied by an "enrichment" factor.

The results show that nutrient depletion is quite severe in sub-Saharan Africa. In almost all of the 38 countries, more than 10 kg of N, 4 kg of P_2O_5 and 10 kg of K_2O per ha per year are being lost. Nutrient depletion rates are most severe in east Africa, where they are almost twice these levels.

The projections for 2000 show an increase in nutrient depletion for all countries, especially those that already have a high depletion rate. The increased use of fertilizer predicted by FAO for 2000 will not be enough to lower the depletion rate and will be more than offset by increased nutrient withdrawal. However, this calculation does not take into consideration any possible improvements in land management that could affect OUT 2 to 5, i.e., the use of crop residues and soil erosion control. Interestingly, a cross check of the model with long term fertilizer experiments in east Africa confirmed the conclusion of declining soil fertility.

A sensitivity analysis showed that soil fertility class and erosion have a high impact on the results. A difference of one soil fertility class can change the balance for a land use system by up to 10 kg N/ha/year.

Through this work, we now have a good indication of the severity and importance of nutrient depletion in some parts of the world. We also have a very useful model to develop and apply elsewhere.

Other assessments of land degradation

Apart from those listed above, there have been few other systematic attempts to assess, map and monitor land degradation. However, there have been several useful national studies. Most of these have been on particular aspects of land degradation, such as the erosion survey of Turkey (Topraksu, 1981).

One regional study of interest is the "Pilot Project for Erosion Mapping and Measurement in Mediterranean Coastal Zones." This FAO-supported UNEP project is refining its methods and correlating mapping exercises in different countries. This project found that several countries were working on the same problems but were using different types of data and working in different ways. A flexible method therefore was developed to allow this work to continue but to bring the results together in a common form. No attempt will be made to give details here but the methodology is represented as a diagram in Figure 2.

Considerations for Future Work in the Assessment and Monitoring of Soil Degradation

From this brief review it is clear that for nearly twenty years there has been a sustained international interest in global assessment of land degradation. Several such assessments have been attempted. Although they have involved several international organizations (including UNEP, FAO, WMO, UNESCO and ISSS), several national institutions, and at least 250 scientists from around the globe, the task has proved difficult and progress has been slow.

In fact, only the ISRIC GLASOD project has succeeded in producing an acceptable global map, although it was on a small scale and was based largely on subjective estimates by regional soil scientists. This shows the difficulty of the task.

What have we learned from this experience, and what problems must be solved if we are to estimate land degradation more accurately and monitor its progress?

1. The most obvious fact to come out of the past work is the complexity of the subject. Land degradation is normally the result of interacting degradation processes, including wind erosion, water erosion, nutrient depletion, and salinization. Often it is difficult to

separate these processes, because one can result from another, and it is difficult to map them together. It is interesting that the GLASOD study concentrated on only four broad types of degradation: water erosion, wind erosion, chemical deterioration and physical deterioration. (Allowance also was made for "stable terrain" and "nonusable wasteland.") The earlier Provisional Methodology for Soil Degradation Assessment and the Provisional Methodology for the Assessment of Desertification used six and seven degradation processes respectively.

So far, it has proved very difficult to assess more than four degradation processes together and map them in an easily understandable form. Perhaps the lesson is that mapping of this type must be kept simple or, alternatively, that different maps must be produced if we are to portray accurately the different processes of degradation.

With the increasing use of Geographic Information Systems and digitized maps perhaps we should not attempt to produce general land degradation maps. Rather, we should make maps of several different degradation processes that can be combined and overlaid to suit our purposes. Such maps could readily be updated to show changes and trends.

2. Another problem of the work to date has been the lack of reliable information as the basis for assessing and mapping the present status, risk and rate of land degradation. Surprisingly, even in countries like the United States, little reliable, usable information has been available (H.E. Dregne, personal communication; International Center for Arid and Semiarid Land Studies, Texas Tech. University, Lubbock). Unfortunately, much of the available data, such as livestock numbers and vegetation cover, are not readily usable. Information on land degradation, such as erosion, is recorded during the soil survey, but it usually is based on subjective, qualitative estimates by the surveyor and frequently is of questionable value. Although data from developed countries may be poor, little usable data is available from many parts of the developing world either.

Initially, high expectations were placed on remote sensing, but so far the results have been disappointing. One possible reason for this is the problem of distinguishing long term land degradation from yearly and seasonal variations. For example, during the dry years in the late 1970s and early 1980s, the Sahara desert appeared to be spreading rapidly. This led to many wild claims of "desertification" and the southward movement of the desert at several kilometers per year. Better rains in following years, combined with lower animal numbers as the result of the droughts, have resulted in a movement back north of this "desertification." From this experience it seems that at least for now, land degradation assessment and monitoring must be based on a few easily measured parameters, careful sifting of what data are available, and subjective estimates by reliable, well-informed

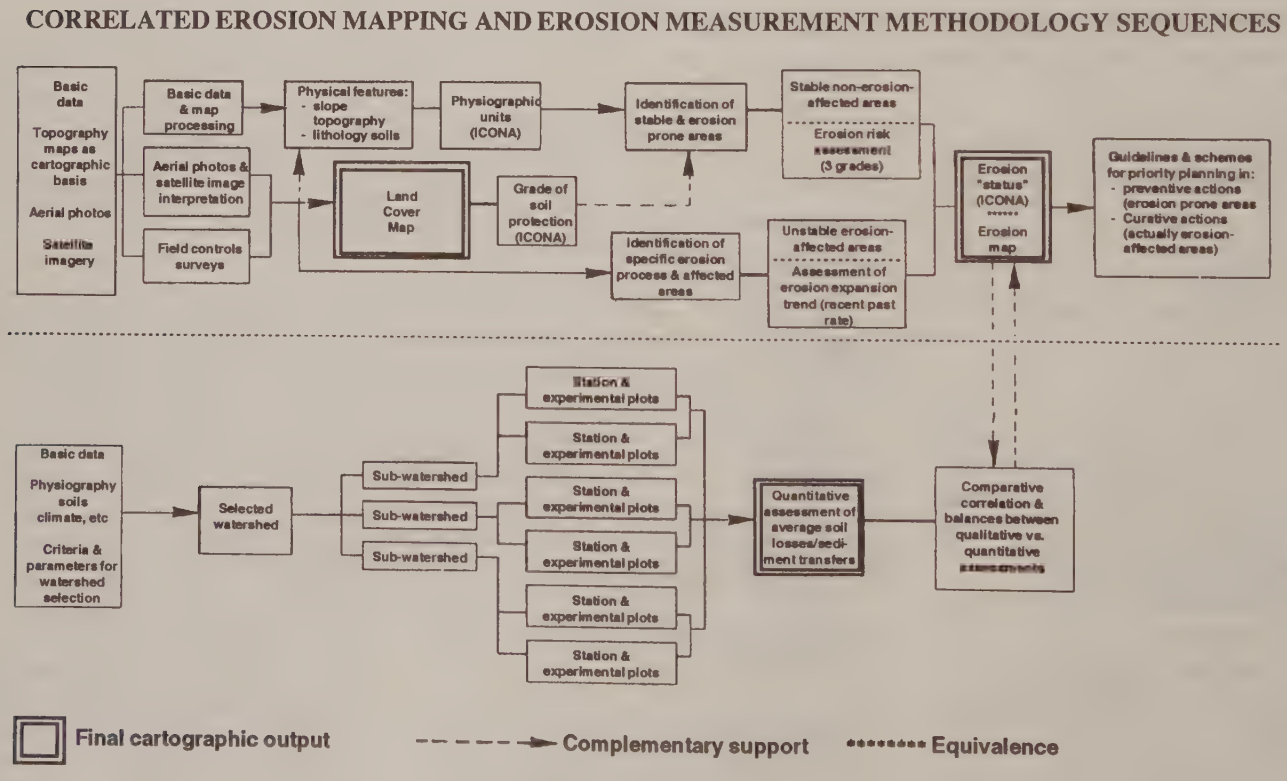
CORRELATED EROSION MAPPING AND EROSION MEASUREMENT METHODOLOGY SEQUENCES
Basic data
Topography maps as cartographic basis
Aerial photos
Satellite imagery
Basic data & map processing
Aerial photos & satellite image interpretation
Field controls surveys
Physical features: - slope topography - lithology soils
Land Cover Map
Physiographic units (ICONA)
Grade of soil protection (ICONA)
Identification of stable & erosion prone areas
Identification of specific erosion process & affected areas
Stable non-erosion-affected areas
Erosion risk assessment (3 grades)
Unstable erosion-affected areas
Assessment of erosion expansion trend (recent past rate)
Erosion "status" (ICONA)
Erosion map
Guidelines & schemes for priority planning in: - preventive actions (erosion prone areas - Curative actions (actually erosion-affected areas)
Basic data
Physiography soils climate, etc
Criteria & parameters for watershed selection
Selected watershed
Sub-watershed
Sub-watershed
Sub-watershed
Station & experimental plots
Station & experimental plots
Station & experimental plots
Station & experimental plots
Station & experimental plots
Station & experimental plots
Quantitative assessment of average soil losses/sediment transfers
Comparative correlation & balances between qualitative vs. quantitative
Final cartographic output
Complementary support
Equivalence

Figure 2. Diagram of methodology used for mapping soil erosion in the Mediterranean basin.

field workers. More reliable assessments are likely to become available only when a network of measuring and monitoring stations is established in representative areas, and all stations gather data on similar parameters and take standardized, comparable measurements.

3. A third lesson to be drawn from past international and national studies is the need to define carefully what is being measured and monitored. The three aspects of land degradation— present status, risk and rate—must be separated. In the past they frequently have been mixed to give confusing and misleading results. In particular, great care must be taken in distinguishing between the present status and the rate of erosion.

   The early attempts to map both rate and status of soil degradation, using the UNEP/FAO provisional soil degradation assessment method, led to confusing and controversial results. In the more recent GLASOD study, the two have been mapped together more successfully but, as a general guide, land degradation status, risk and rate should be assessed and mapped separately.

4. To date, most assessments either explicitly or implicitly have been aimed at measuring human-induced land degradation. For example, the GLASOD map is called "World Map of Human Induced Soil Degradation." This raises the question of why we should assess only human induced processes. Another question that perhaps is more important is: how do we clearly distinguish between the human and natural forms of land degradation?

   Areas most seriously affected by soil erosion include the Himalayas, the Andes and New Zealand. All are geologically active and no doubt would be eroding quite rapidly without human influence. According to a recent World Bank study on watershed development in Asia (Doolette and Magrath, 1990), the Hindu-Kush-Himalaya range is in a continuous state of formation as tectonic drift drives the Indian Plate under the Eurasian Plate at a rate of 5 cm per year, lifting the Himalayas 1 cm per year. With geological activity of this magnitude, stream bed erosion, gully erosion and mass movements inevitably will take place naturally. It is probable, as claimed in this World Bank study, that human activity has done little more than speed up what was going to happen anyway.

   The study made the following point: "Disentangling the impact of upland land use from other factors in determining the frequency and severity of downstream flooding has proved an elusive task. . . . A consensus among policy analysts is now starting to emerge, however, that suggests that agriculture and forestry in upper watersheds play a relatively minor role in exacerbating the effects of major catastrophic flood events."

   This was written in relation to the Himalaya region, which is an extreme case. Nevertheless, it does show that we should not overlook the extent and possible effects of natural or geologic erosion and separate it, if possible, from human induced erosion.

5. To date, most global work has concentrated on assessing the present situation, establishing a baseline. Little, if any, systematic work has yet gone into monitoring. However, in line with the World Soil Policy, UNEP is attempting to monitor global soil and land resources (UNEP, 1982). The production of the GLASOD map is an important step in this direction. But even with an assessment as a baseline, the question remains of how we are to systematically monitor what is happening. As mentioned above, accurate monitoring may be possible only when properly manned and equipped monitoring stations are established in representative areas. The establishment of such stations would be expensive, and is not likely to happen soon.

   Meanwhile, it seems that we must search for cheap and easy indicators. What might these be? The density of vegetative cover is usually a good indicator, and it can be assessed with reasonable accuracy by remote sensing. The problem is that in the vast semi-arid regions, which are highly vulnerable to land degradation, the vegetative cover varies considerably from season to season and year to year because of rainfall variations. Unless vegetation and rainfall patterns are compared for several years, or even decades, the indicated changes can be misleading, so that trends are hard to assess. Monitoring of soil organic carbon levels has been suggested as a quick and simple way of monitoring soil conditions. However, attempts to use organic carbon levels as an indicator have presented problems: soils rich in calcium carbonate can give misleading results, organic carbon levels can fluctuate very rapidly in tropical conditions and the analytical results obtained from some places have been very questionable (H.E. Dregne, personal communication).

Conclusions

Over the last twenty years several attempts have been made to assess systematically the global extent of land degradation, but to date nothing has been done globally to monitor changes. Global assessments of land degradation have proved very difficult: sufficient, reliable data are not available to support complex methods of assessment, and the usefulness of remote sensing so far has been limited.

Experience to date shows that great care must be taken in deciding which degradation processes to measure and in insuring that the three aspects of degradation (status, rate, and risk) are not confused. On the other hand, much valuable experience has been gained, and the recently completed GLASOD study has resulted in the first acceptable map of global land degradation. This will provide a valuable baseline for future work.

As to the future, the increasing use of geographical information systems is providing much greater opportunities for the storage and manipulation of data. This should greatly help future work. The main problem still to be overcome is the lack of reliable, usable and comparable data. This is likely to be overcome fully only when properly equipped and manned stations are established in representative areas to monitor land degradation. This is probably a long way off, so that work for the

present should concentrate on developing and refining simple methodologies that can make the best use of what data are available and of the best, informed judgements of experienced workers in this field.

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UPCOMING EVENTS

November 1-6, "Farming Systems Options for U.S. Agriculture," the national meetings of the American Society of Agronomy, will be held in Minneapolis, MN; contact ASA, 677 South Segoe Road, Madison, WI 53711; (608) 273-8080.

November 1-3, Fourth National Pesticide Conference will be held in Richmond, VA; contact Diana Weigmann, Virginia Polytechnic Institute, 617 North Main St., Blacksburg, VA 24060-3397; (703) 231-5624.

November 5-7, Acres U.S.A. 1992 Conference will be held in Kansas City, MO; contact: Acres U.S.A., P.O. Box 9547, Kansas City, MO 64133; (816) 737-0064.

November 6-8, 7th Annual Sustainable Agriculture Conference, "Carolina Agriculture: In Transition to Sustainability," will be held at Winthrop University, Rock Hill, S.C.; contact Carolina Farm Stewardship Association, 115 W. Main St., Carrboro, N.C. 27510; (919) 968-1030.

November 14-15, Land Stewardship Project's 10th Anniversary and Conference will be held in Arden Hills, MN; preregistration is required. For a brochure and registration form, contact the Project, 14658 Ostlund Trail N., Marine on St. Croix, MN 55047; (612) 433-2770.

November 14-15, Organic Farmer to Farmer Conference will be held at Northern Pines Conference Center, Raymond, ME; contact Maine Organic Farmers and Gardeners Association, P.O. Box 2176, Augusta, ME 04338-2176; (207) 622-3118.

November 16-21, "Organic Agriculture, A Key to a Sound Development and a Sustainable Environment," sponsored by the International Federation of Organic Agriculture Movements, will be held in Sao Paulo, Brazil; contact: General Secretariet, clo Okoszentrum Imsbach, D-6695 Tholey-Theley, Germany; phone: 49-6853-5190.

December 5-11, International Conference on Nutrition, sponsored by the U.N. Food and Agriculture Organization and the World Health Organization, will be held in Rome, Italy; contact Timmie Jensen, FAO, 1001 22nd St., NW, Washington, D.C. 20437; (202) 653-2452.

December 9-11, "Fruits and Vegetables Organically Produced in Europe," the third technical seminar of the Research Group on Organic Farming, will be held in Avignon, France; contact GRAB, Agroparc, BP 131, 84146 Montfavet, France.

January 25-29, 1993, "Soils and Society: Responsible Management" will be held at North Carolina State University, Raleigh, N.C.; contact: TropSoils Management Entity, Box 7113 Daniels Hall, North Carolina State University, Raleigh, N.C. 27695-7113; (919) 515-3922.

February 21-24, 1993, "Agricultural Research to Protect Water Quality," sponsored by the Management Systems Evaluation Area Program and the Soil and Water Conservation Society, will be held in Minneapolis, MN; contact: SWCS, 7515 Northeast Ankeny Road, Ankeny, IA 50021-9764; 1-800-THE-SOIL.

March 1, 1993, "Alternative Agriculture Policy: A New Time to Choose," the 10th annual conference of the Institute for Alternative Agriculture, will be held in Washington, D.C.; contact the IAA, 9200 Edmonston Road, #117, Greenbelt, MD 20770; (301) 441-8777.

Characterization of soil quality: Physical and chemical criteria

M.A. Arshad and G.M. Coen

Abstract. The impact of soil degradation on human welfare and the global environment presents a major challenge. A significant decline in soil quality has occurred worldwide through adverse changes in its physical, chemical and biological attributes and contamination by inorganic and organic chemicals. There is a need to develop criteria to evaluate soil quality so that the progress of any corrective action required by the international community can be monitored.

There currently are no generally accepted criteria to evaluate changes in soil quality. This lack impedes the design and evaluation of meaningful soil management programs. This paper examines the principal physical and chemical attributes that can serve as indicators of a change in soil quality under particular agroclimatic conditions. Proposed indicators include soil depth to a root restricting layer, available water-holding capacity, bulk density/penetration resistance, hydraulic conductivity, aggregate stability, organic matter, nutrient availability/retention capacity, pH, and where appropriate, electrical conductivity and exchangeable sodium. We also discuss the justification for selecting these key attributes, their measurement, critical limits for monitoring changes in soil productivity, and future research needs in soil quality.

Key words: soil quality evaluation, soil degradation

Introduction

There is growing concern about soil degradation or decline in soil quality and its impact on human welfare and the global environment (Brundtland, 1987; Benbrook, 1991; FAO/UNEP, 1983; Lal and Stewart (eds), 1990; Lebel and Kane, 1987, Worldwatch Institute, 1990). The main degradation processes are soil erosion, compaction, acidification, salinization and sodification, and water-logging (FAO/UNEP/UNESCO, 1979; Lal and Stewart, eds., 1990). Soil erosion is perhaps the most destructive of these, and has the most widespread impact on soil quality. Degradation can affect soil properties, hydrology and vegetation.

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Soil quality can be expressed in terms of the sustaining capability of a soil to accept, store and recycle water, minerals and energy for production of crops at optimum levels while preserving a healthy environment. Key attributes of soil quality include physical, chemical and biological properties. Quality of soils also depend on climate, landform and, most importantly, people, because it is human decisions and actions that ultimately determine whether an agricultural production system is sustainable on a given soil.

Currently there are no acceptable criteria to evaluate changes in soil quality. Lack of scientifically established criteria is adversely affecting the design and evaluation of meaningful soil management programs. This paper examines physical and chemical attributes that can indicate changes in soil quality under a given set of agroclimatic and socioeconomic conditions.

Rationale for Selecting Soil Quality Parameters

The need for soil quality evaluation has been strengthened by growing global concern about soil degradation. Therefore, it is desirable to examine the changes caused by different degradation processes that result in decline of soil productivity or soil quality. Principal soil properties most affected by soil degradation processes could then form key attributes for soil quality evaluation. A list of principal physical and chemical properties adversely affected by soil degradation processes is given in Table 1.

Although many soil characteristics are affected by degradation processes, the measurable soil attributes that are primarily influenced are: soil depth, water-holding capacity, bulk density, hydraulic conductivity, nutrient availability and retention capacity, organic matter, pH and electrical conductivity. The extent and degree of changes in these soil quality parameters depend on agroclimatic factors, hydrogeology, cropping and cultural practices, and management systems. The relationships among these factors are schematically illustrated in Figure 1.

Characterization of Soil Quality

Site characteristics

Site information is essential to relate soil quality attributes to crop performance and to environmental effects. For example, even though a soil is excellent, optimum levels of crop production may not be possible because of inadequate rainfall or temperature. Attributes of primary importance are as follows:

Terrain: location (longitude, latitude, elevation and legal location), land form (parent material and surface features), and topographical characteristics (slope position, steepness and length).

Climate: precipitation (amount, distribution, intensity), potential evaporation and temperature (heat units, frost-free period, growing season), energy (radiation, daylength, sunshine hours), climatic hazards (rain and hailstorms), wind speed and direction, relative humidity, and soil temperature.

Hydrology: surface drainage, hydrogeology, depth to water table, and incidence of flooding.

Socioeconomic factors

Crop production systems, operator skills, and management practices directly affect soil quality. If the goal is to improve the environment then soil quality is likely to improve. If the goal is exploitation of natural resources, then soil degradation will likely occur. The absence of information on land managers' attitudes, knowledge and practices as they affect soil quality, combined with scientists' traditional focus on the soil rather than its managers, is a reflection of the serious state of soil degradation. Consequently, the greatest opportunity for reversing degradation and enhancing soil quality lies in this area. Information should be collected on the following:

Land use: type of farm operations (e.g., dryland, irrigated, grain, livestock, mixed), land use history (years farmed, changes in farming systems), and major land improvements or disturbances (drainage, flooding, erosion, etc.).

Operator: goals (economic, agronomic, environment, quality of life), attitudes, knowledge (education, experience), and sources of information (extension, demonstration, research, peers, etc.)

Management: water management strategies, crop management (rotations, weed control, varieties, etc.), tillage (no-till, conventional, equipment used), livestock (pasture, hay, manure disposal) and soil conservation practices.

Table 1. Principal physical and chemical properties adversely affected by soil degradation processes responsible for decline in soil quality.

Soil degradation process	Soil properties adversely affected
Erosion	Depth—decrease in rooting volume, topsoil loss.
	Water-holding capacity—decrease due to decline in organic matter, fine mineral colloids, aggregation and depth.
	Organic matter—decline in nutrients and nutrient retention capacity, biological degradation.
	Cation exchange capacity—the most reactive colloids lost, leaving sand and gravel with little nutrient retention capacity.
	Bulk density—more compact and dense horizons exposed.
	pH—increase or decrease, depending on underlying materials.
	Combination of above—structural collapse and poor tilth.
Compaction	Bulk density and penetration resistance—increase results in low oxygen diffusion and restricted root development.
	Infiltration rate—decline in water entry into the soil decreases water storage and increases runoff and soil loss.
	Hydraulic conductivity—poor drainage, low oxygen diffusion rate, cold soils.
Acidification	pH decrease.
	Nutrient availability.
Salinization	Electrical conductivity—increase.
Sodification	pH—increase.
	Hydraulic conductivity—decrease due to dispersion of soil colloids resulting from increase in ESP.
	Bulk density—increase due to compact surface/subsurface horizons.
Water-logging	Aeration, nutrient availability.
Chemical degradation	Nutrient depletion, nutrient imbalance, toxic chemicals affecting quantity and quality of crops.
Biological degradation	Organic matter, microbial biomass and diversity of soil fauna affect soil structure, nutrient release, nutrient retention and other properties.

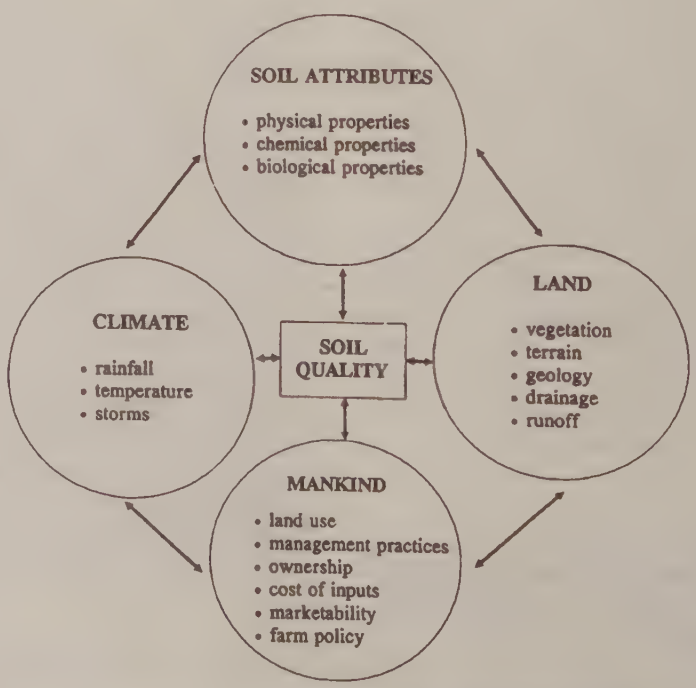

Figure 1. Interrelationships of principal factors affecting soil quality.

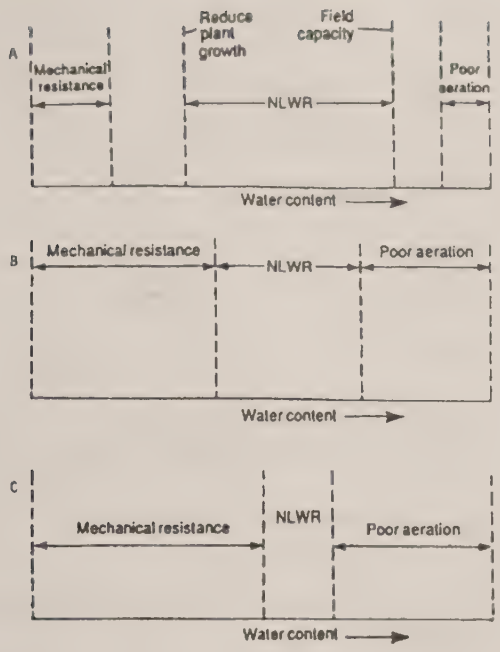

Figure 2. Generalized relationships between soil water content and factors restricting plant growth in a soil. The limiting factors progressively increase in magnitude, resulting in a decrease in the non-limiting water range (NLWR) in conditions A to C. (from Letey, 1985).

Physical and chemical attributes of soil quality

Most soil physical, chemical and biological properties are related to soil quality. Also, there are several interacting factors that affect a particular soil attribute. For example, the non-limiting water range (NLWR) may be affected by aeration or mechanical resistance (Figure 2), particularly in poorly structured soils with high bulk density (Letey, 1985). Similarly, tilth is a physical condition of a soil resulting from combined action of physical, chemical and biological processes called "tilth-forming processes" (Karlen et al., 1990). However, broad attributes such as NLWR and soil tilth cannot be assessed without estimating their specific component attributes. Therefore, it is more appropriate to use specific soil quality attributes that can be quantified. It may be possible to calibrate field morphological estimates of NLWR and tilth with their specific component attributes to provide a qualitative estimate of soil quality.

Key soil physical and chemical attributes that can be used to assess soil quality, and the factors affecting these attributes are as follows:

1. Soil depth: Depth of soil to a layer that would restrict root growth or water movement strongly affects crop production and is an important indicator of soil quality. In a study conducted by Bowman et al. (1990), wheat yield declined by almost 57% with a 50% decrease in soil depth (Table 2). Factors that influence this attribute include stones, bedrock, hard pan, high salt contents, frozen layer, and water table.

2. Water holding capacity and water retention characteristics: Soil texture, organic matter, soil structure (particularly at low tensions), and mineralogy have major influences on moisture retention. Crop yield frequently is directly related to the amount of available soil moisture (Figure 3). A decrease in soil depth reduces water holding capacity and crop yields (Table 2).

3. Structural type/aggregate stability: The amount and quality of soil organic matter (SOM) affects structural stability. The main organic components that stabilize soil aggregates include organo-mineral complexes, polysaccharides, and root exudates. Biological activity, the amount and type of clays, amorphous inorganic materials, and type and amount of electrolytes affecting colloidal dispersion are other important factors that affect stability of soil aggregates.

4. Hydraulic conductivity (K_{sat}) and infiltration rate: Hydraulic conductivity is affected by texture, organic matter, mineralogy (expandable vs non-expandable clays), soil porosity and soil structure. It is greater if the soil is highly porous or aggregated than if it is compact and dense. K_{sat} and infiltration rate are affected not only by total porosity but also by the size of the conducting pores. Because of various chemical, physical and biological processes, K_{sat} may change as water infiltrates through the soil and solute concentration changes. In general, K_{sat} decreases with decreasing concentration of electrolytes because of swelling and dispersion of colloids.

5. Bulk density/penetration resistance: Texture, porosity, organic matter, aggregation and structural class (massive, granular, etc.) affect soil compaction and thus bulk density. Crop growth usually is harmed by soil compaction; nevertheless a maximum yield will not be obtained from a soil directly after plowing, because the

Table 2. Changes in selected physical properties (0-30 cm) and wheat yields with long-term cultivation, Colorado (Bowman et al., 1990).

Years of cultivation	Average depth to lime (cm)	Water content (kg kg^{-1}) ----------MPa----------		Wheat yield (kg ha^{-1})
		-0.03	-1.5	
0	60	0.130	0.070	-
3	55	0.080	0.068	2700
20	44	0.098	0.065	1500
>60	30	0.086	0.055	1150

soil is too loose. An optimum degree of compaction is required for maximum yield (Figure 4).

Root growth is significantly affected by mechanical resistance (Ehlers et al., 1983). Soil impedance as measured with a constant-rate penetrometer has been reported to be more sensitive than bulk density to crop and tillage management systems (Hammel, 1989; Bauder et al., 1981).

6. Organic matter, a physical, chemical and biological attribute: Organic matter improves soil quality by increasing aggregation, water infiltration and retention, nutrient content, buffering capacity and soil biota activity. Climatic conditions, effective soil moisture and vegetative cover exert a dominant influence on the amount and quality of SOM. Texture, drainage, cropping systems and tillage management also affect the level of organic matter.

7. Cation exchange capacity (CEC)/ nutrient retention capacity: Retention and release of several nutrients essential for plant growth depend on the exchange characteristics of soils. Soil texture and the amount and type of clay minerals and organic matter are the major factors affecting CEC.

8. pH and base saturation: Availability of nutrients and different soil processes are greatly influenced by pH and percentage base saturation. Plants vary considerably in their tolerance of an acidic or alkaline soil environment (Doll, 1964). Therefore, a change in pH may have a positive or negative effect on soil quality, depending on the cropping system. Important factors affecting pH include parent material (e.g., pyritic shale), alkali salts, drainage, weathering, fertilizers, proximity to metal ore smelters, and residual base saturation capacity.

9. Electrical conductivity (EC): Soil salinity is a major constraint to plant production in some arid regions of the world. In such areas it should be included as a key attribute in assessing soil quality. Factors affecting it include types of salts (e.g., the ratio of Na^+ to $Ca^{2+} + Mg^{2+}$ ion concentrations in equilibrium extracts, or sodium adsorption ratio [SAR]), drainage, type of parent material and irrigation water quality.

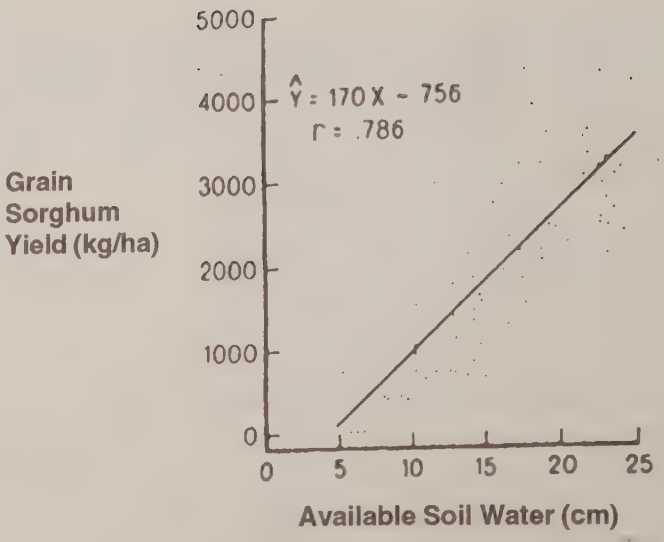

Figure 3. Effect of soil water (0 to 1.8 m depth) at seeding on dryland grain sorghum yield (Jones and Hauser, 1975).

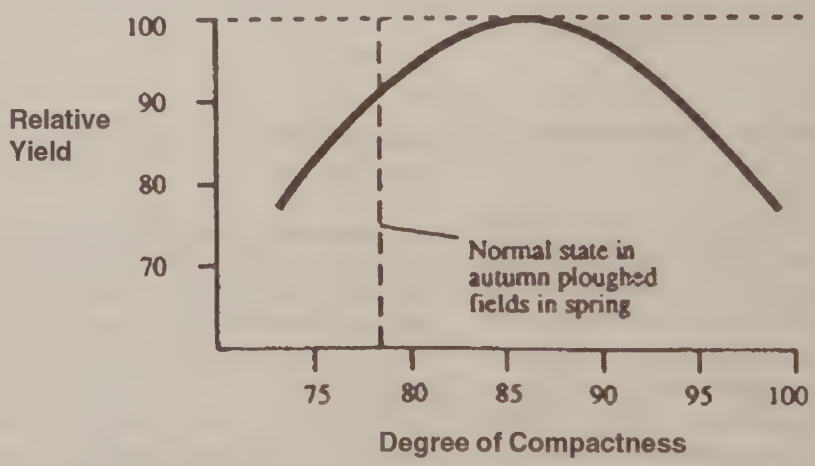

Figure 4. General relationship between degree of compactness and yield (after Arvidsson and Håkansson, 1991).

10. Exchangeable sodium percentage (ESP): Percentage of exchangeable sodium in relation to other cations on the exchange complex has a significant impact on soil dispersion, aeration, compaction and water infiltration. Therefore, soil structure and plant growth can be negatively affected by high ESP. The extent of decline varies with plant species (Figure 5) and agroclimatic conditions.

Methods for Assessing Soil Quality

Qualitative methods

Many physical attributes of soils can be estimated well enough by calibrating qualitative observations/features against measured values. Detailed procedures are described by McKeague et al. (1986).

Visual, morphological features that can be used by producers and extension workers to indicate changes in soil quality should form an essential component of the monitoring program. This is particularly relevant in regions where resources are limited. Observations such as surface sealing/crusting, rills, ponding of water, vegetative cover and other features can reveal possible causes. For example, soil crusting or surface sealing may indicate high SAR, ESP, dispersable clays, loss of organic matter, aggregation and low hydraulic conductivity. A checklist of characteristics that can provide useful information is given in Table 3.

Quantitative methods

Procedures for measuring most soil attributes are given in Methods of Soil Analysis, Part 1 (Klute, (ed.), 1986) and Part 2 (Page (ed.), 1982). A brief description of methods for proposed attributes to assess soil quality is given in Table 4. Modifications may be required under certain circumstances.

Critical limits

Selection of critical limits for soil quality parameters poses several difficult problems. The ability to supply moisture, nutrients and physical rooting support in the absence of toxic substances can be affected by many chemical, physical and biological parameters. A detrimental change in any of these can reduce the quality of the soil, but the quantitative values beyond which a further reduction in these characteristics is limiting depend strongly on the crop. For example, a pH below about 6.5 reduces the yield and vigor of alfalfa, but pH must drop below about 4.0 before critical yield reductions occur in blueberries (Doll, 1964). A critical limit of a characteristic can also be ameliorated or exacerbated by limits of other chemical or physical properties. For example, a negative yield response of a given crop to soil salinity may be increased or reduced by lower or higher percentages of available moisture.

Given the complexities of yield response to critical soil parameter values, perhaps the best we can hope for globally is a set of guidelines that can help set limits for defined crop/environment situations. First, define an appropriate crop/environment grouping such that the response of each crop in the group will be similar to other crops in the group when soil parameter values are changed. Then select the 5 or 6 soil or landscape parameters that when modified through human-induced soil degradation processes cause the greatest decrease in crop yield. Next, ascertain the value of each parameter beyond which further degradation causes an incrementally greater yield reduction. In some situations, these evaluations may be carried out using experimental method with rigorous numerical and statistical techniques. In others, it may be appropriate to use the experience of farm operators or advisers.

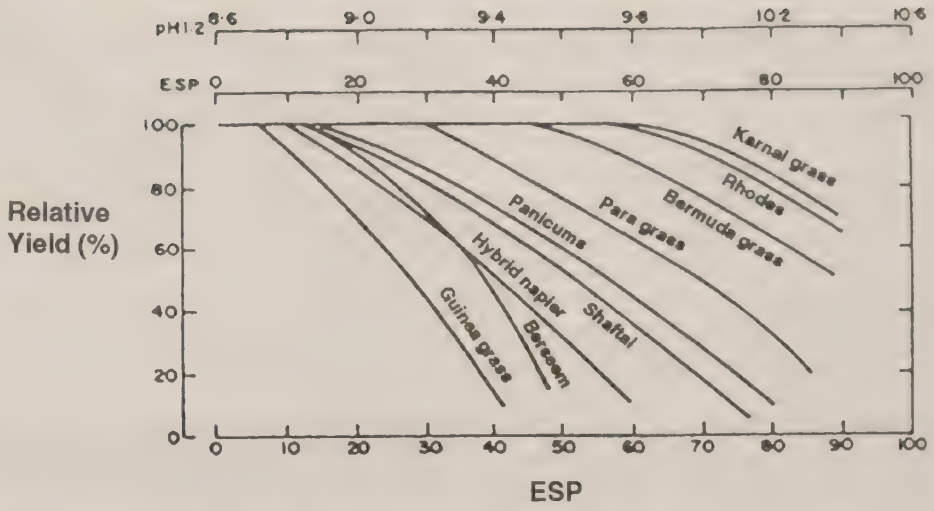

Figure 5. Relative tolerance of grasses in alkali soils (after Kumar and Abrol, 1989).

Research Needs

1. We need data on critical limits of major physical and chemical attributes for various crop production systems under different agroclimatic regions.
2. To quantify and evaluate changes in soil quality, various combinations of farming systems and their interactions with different soil attributes must be understood.

Table 3. Methods for soil quality assessment—qualitative methods.

Observable features (examples)	Possible causes
Soil crusting; surface seal	loss of organic matter, aggregation, low hydraulic conductivity, high ESP, high dispersable clays
Rills, gulleys, stones on surface, exposed roots, uneven topsoil	water erosion
Ripple marks, sand dunes, sand cover on soil surface, parallel furrows with notches in heavy soils, sand against plant stems, hedges, plant damage, etc.	wind erosion
Salt crust on soil surface; salt-tolerant plants.	salinization
Nature of crust	
- moist & dark	$MgCl_2$, $CaCl_2$
- fine crystalline	NaCl, Na_2SO_4
- dark	Na_2Co_3 (black alkali; dissolution of SOM)
Acid tolerant plants, lack of fertilizer response	acidification, chemical degradation of soils
Standing water, ponding of water, poor and patchy crop stand	poor drainage, compact/hardpan structural deterioration

Table 4. Methods for soil quality assessment—quantitative methods.

Soil attribute	Method of measurement
Soil depth	Measure depth to a layer that would restrict root growth and water movement. Record the type of layer: bedrock, tillage pan, fragipan, frozen layer, etc.
Water holding capacity (WHC)	Use soil cores of horizons to 100 cm. Measure water retention at 0, -10, -33, -100, -400 and -1500 kPa. Calculate "available water" at -10 to -1500 kPa and air porosity at -10 kPa.
Aggregate stability	Wet-sieving method described by Kemper and Rosenau (1986). Measurement should be made on samples with the same soil water content as discussed by Gollany et al. (1991).
Hydraulic conductivity	Hydraulic conductivity (K_{sat}) and infiltration rate can be measured by using an adaptation of the Guelph permeameter (Reynolds and Elrick, 1991). Ideally, infiltration rates should be measured at several times during the season and K_{sat} at different depths.
Bulk density/soil impedance	Same cores as in WHC can be used for bulk density. Measure soil impedance with cone penetrometer (Bradford, 1986).
Organic matter	Total C and N by dry combustion in a Leco CHN Analyzer or other suitable method (Nelson and Sommers, 1982). Use subsamples of Ap horizon (0-7.5, 7.5-15 cm).
Cation exchange capacity (CEC)	Exchangeable Ca, Mg, Na and K by NH_4OAC for non-saline soils of pH ≥5.5 ($CaCl_2$) or pH >6.0 (H_2O). In non-saline soils of pH <5.5, use neutral salt such as NaCl. Determine Ca, Mg, K and Al. The sum of cations extracted gives an adequate measure of CEC.
pH	All horizons to 100 cm; preferably use 0.01M $CaCl_2$. If salinity is to be measured, pH of saturated paste may be measured.
Electrical conductivity	Use saturated paste as in Rhoades (1982), or 1:2 soil: water suspension. Measure soluble cations, Ca, Mg, Na and K by AA. Measure SO_4, Cl, HCO_3 if EC >4 mS/cm.
Exchangeable sodium percentage (ESP)	Calculate from data under cation exchange capacity (CEC) as given above.

3. A minimum set of data must be identified to develop scientifically valid criteria for soil quality assessment and monitoring. The data obtained would be useful to develop models to predict the rate of change (positive or negative) in soil quality. Emphasis should be placed on the quality rather than quantity of the data.
4. Long-term experiments (20-30 years) should be conducted to establish the positive and negative effects of different soil and crop management practices on soil attributes so that appropriate action can be taken accordingly.
5. Research should be undertaken to develop simple techniques that can be used by the producers and extension workers, particularly where resources are limited.

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RESOURCES

Food Safety: The Interpretation of Risk, a 23-page report from Council For Agricultural Science and Technology, is available for $8 from CAST, 137 Lynn Avenue, Ames, IA 50010-7197; (515) 292-2125.

Basic Guide to Pesticides: Their Characteristics and Hazards, a 450-page book compiled by the Rachel Carson Council, is available for $39.50 plus $2.50 shipping/handling from Taylor & Francis, 1900 Frost Road, #101, Bristol PA 19007-1598; call 1-800-821-8312.

Sustainable Agriculture Events Calendar is an electronic/computer bulletin board sponsored by Iowa State University Extension and the Leopold Center for Sustainable Agriculture. To access the listings or place events on the calendar, call Rich Pirog, (515) 294-1854; or Jerry DeWitt, (515) 294-7801.

A Guide to Sustainable Agriculture Practices, a cooperative project of the Illinois Sustainable Agriculture Society and the Illinois Department of Energy and Natural Resources, is available from the Society, P.O. Box 500, Rochester, IL 62563; (217) 498-7422.

Increasing Organic Agriculture at the Local Level, a 116-page book published by the Santa Barbara Safe Food Project and the Community Environmental Council, is $16 from the Council, 930 Miramonte Drive, Santa Barbara, CA 93109; (805) 963-5452.

The Thompson Farm On-Farm Research, 1991, a 68-page brochure, is available for $7.95 from Rodale Institute, 222 Main Street, Emmaus, PA 18098; (215) 967-5171.

Issues in Sustainable Agriculture: What Are the Next Steps?, a report on a symposium held in June, 1991, is available from the Michael Fields Agricultural Institute, 2493 County Road ES, East Troy, WI 53120-9271; (414) 642-3303.

Pesticides In Our Communities: Choices for Change, a community action guide, is available for $4 plus $1.50 postage/handling from CONCERN, Inc., 1794 Columbia Road, NW, Washington, D.C. 20009; (202) 328-8160.

Indiana On-farm Demonstration and Research Project, 1991 Results, a 33-page report on a cooperative project of the Indiana Sustainable Agriculture Association and the American Farmland Trust, is available for $5 from AFT, Center for Agriculture in the Environment, P.O. Box 987, DeKalb, IL 60115; (815) 753-9347, or AFT, National Office, 1920 N St., NW, #400, Washington, D.C. 20036; (202) 659-5170.

Suppliers of Beneficial Organisms in North America, a 31-page booklet, is available free from the Dept. of Pesticide Regulation, California Environmental Protection Agency, ATTN: Beneficial Organisms Booklet, 1220 N St., P.O. Box 942871, Sacramento, CA 94271-0001; (916) 654-1141.

Farm, Rural Economy, and Policy Implications of Sustainable Agriculture in South Dakota, published by the Agricultural Experiment Station, South Dakota State University, and USDA, is available free by sending a mailing label and $.98 postage to Bulletin Room, Lincoln Music Hall, South Dakota State, Brookings, S.D. 57007.

Increasing Organic Agriculture at the Local Level, a 116-page book published by the Santa Barbara Safe Food Project and the Community Environmental Council, is $16 plus $2 shipping and handling from the Council, 930 Miramonte Drive, Santa Barbara, CA 93109; (805) 963-5452.

Precision Farming Variable Cropland for Profit and Conservation, a 144-page proceedings from a February conference at Washington State University, is $4 from Baird Miller, Department of Crop and Soil Sciences, WSU, Pullman, WA 99164-6420.

A Rural Studies Bibliography, a listing of 163 books and articles, and **Directory of Rural Studies Scholars and Educators** are available free from Rural Information Center, Room 304, National Agricultural Library, 10301 Baltimore Blvd., Beltsville, MD 20705-2351.

Sustaining America's Agriculture: High-Tech & Horse Sense, a 30-minute video produced by the EPA, Soil Conservation Service and Winrock International, is available from National Association of Conservation Districts by calling 1-800-825-5547.

Sustainable Farming Guide Book is available for $8 from the Minnesota Department of Agriculture, Energy and Sustainable Agriculture Program, 90 West Plato Blvd., St. Paul, MN 55107.

Sustainable Agriculture in the 21st Century: Will the Grass Be Greener? by Dr. Charles M. Benbrook, is available for $5 from the Humane Society of the United States, 2100 L St., NW, Washington, D.C. 20037; (202) 452-1100.

Managing Cover Crops Profitably, a 114-page publication of the LISA Program, is available for $9.95 from Sustainable Agriculture Publications, Department of Plant and Soil Science, University of Vermont, Burlington, VT 05405.

California Farmer-to-Consumer Directory for 1992 is available at no charge from the University of California Small

Farm Center, University of California, Davis, CA 95616; (916) 757-8579.

The GreenDisk, an environmental journal on computer disk, summarizes the work of hundreds of organizations and government agencies and is available for $35 a year (6 disks). Contact: Green Disk, Box 32224, Washington, DC 20007; (202) 337-4175.

Unnecessary Risks: The Benefit Side of the Pesticide Risk-Benefit Equation, is available for $10 from National Coalition Against the Misuse of Pesticides, 701 E St., SE, Washington, DC 20003; (202) 543-5450.

1992 National Directory of Organic Wholesalers is $29.95 from California Action Network, PO Box 464, Davis, CA 95617; (916) 756-8518.

Minnesota Green Pages, a directory of sustainable agriculture, food, and the environment, is $2 from the Minnesota Chapter of the International Alliance For Sustainable Agriculture, Newman Center, University of Minnesota, 1701 University Avenue South East, Minneapolis, MN 55414; (612) 331-1099.

Organic Agriculture Worldwide, directory of the member organizations and corporate associates of International Federation of Organic Agriculture Movements, is $15 from IFOAM, Okozentrum Imsbach, D-6695 Tholey-Theley, Germany.

Alternative Livestock Production, Processing, and Marketing for Western Colorado, a two-hour video, is $13 from Bob Bishop, Extension Director, San Miguel Basin Extension Fund, PO Box 130, Norwood, CO 81423.

Biological Control of Turfgrass Diseases is $5 from Publications Distribution Center, Cornell Business and Technology Park, Cornell University, Ithaca, N.Y. 14853; (607) 255-2080.

Alternatives in Insect Management: Biological and Biorational Approaches is $6 from the University of Illinois Office of Agricultural Communications and Education, 69N2 Mumford Hall, 1301 W. Gregory Dr., Urbana, IL 61801; (217) 333-2007.

Do Federal Policies Hurt Family Farms?

In a series of just-completed hearings and a symposium to be held in late October, the Joint Economic Committee (JEC) of the U.S. Congress is examining the role of federal farm policies in promoting or discouraging family farming. Chaired by JEC Vice Chairman Rep. Lee H. Hamilton (D-IN), the most recent hearing set out to "define a U.S. farm system that is internationally competitive, environmentally benign, and promotes family farming."

"Family farm decline has been fostered by public policy, as well as forces inherent to capitalist economies," said Chuck Hassebrook of the Center for Rural Affairs, Walthill, NE, a witness at the hearing. "In many respects, [U.S. farm policy] has been biased in favor of bigness and has subsidized the use of capital to replace people beyond the degree necessary for an efficient agriculture.

"Consequently, it has fostered the industrialization of agriculture—including the concentration of the ownership of agriculture assets into fewer and larger operations, reduced numbers of farms, reduced opportunities for new people to enter family farm agriculture, and the growth of an industrial class structure in agriculture, with increased separation between farm labor and the ownership and control of farm assets."

The link between the economic attractiveness of sustainable farming systems and the structure of agriculture and rural communities was detailed by another witness, Thomas Dobbs, Professor of Agricultural Economics at South Dakota State University, who said, "There are major opportunities for an enhanced federal government role in fostering sustainable farming systems and economically viable rural communities. These opportunities involve giving appropriate shape to public policies and providing adequate financial support for institutions serving agriculture."

Dobbs called for increasing funding for the SARE (formerly LISA) program, and giving the National Research Initiative competitive grants program a greater emphasis on multidisciplinary research dealing with problems of agricultural sustainability.

At a symposium in late October, the JEC will take a broader perspective "on the impact of agricultural industrialization on family farms, and how federal policy can be changed to support family farming," according to Stuart Smith of the JEC staff. The symposium will have three phases: the presentation of papers, response to the papers from a panel, and extensive questions from the audience, which will include the public.

The JEC will make recommendations to Congress on the effect of federal agriculture policy on family farming, based on the hearings and the symposium. For more information about the October symposium, contact Stuart Smith at (202) 224-5171.

Letters To The Editor Invited

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Soil biological criteria as indicators of soil quality: Soil microorganisms

Suzanne Visser and Dennis Parkinson

Abstract. Diverse soil microbiological studies have attempted to assess deterioration or improvement in soil quality. These studies have been done on three levels: population level studies of the dynamics of species that are presumed to be important or sensitive; community level studies of microbial community structure, such as species diversity and frequency of occurence of species; and ecosystem level studies of a range of soil processes. We suggest that ecosystem level approaches offer the best possibilities for rapidly assessing changes in soil quality. Data from such studies will allow researchers to decide whether to proceed with population or community level studies.

Key words: soil bacteria, soil fungi, total microbial biomass, carbon cycling, nitrogen cycling, nutrient leaching, soil enzymes

Introduction

Since the discovery of the complex microbial communities in soil, there have been many attempts to use them to predict soil fertility. Waksman (1927) considered in detail whether quantitative methods for studying soil microorganisms could indicate the actual or potential fertility of a particular soil. Reviewing literature published between 1902 and 1926, he considered several criteria as indicators of fertility: numbers of microorganisms, nitrifying capacity, CO_2 evolution (with or without added substrates), cellulose decomposing capacity, nitrogen fixing and mannite decomposing capacity, catalytic action (production of O_2 from H_2O_2), and oxidizing and reducing power. However, he emphasized that because fertility also is affected by physical and chemical soil factors, climate, and the crop, it is difficult to generalize about how well such microbiological criteria indicate fertility.

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In the 65 years since Waksman's book, our knowledge of soil processes and interactions resulting from microbial and faunal activities has increased greatly. The critical roles that bacteria and fungi play in cycling organic matter and nutrients in natural and agricultural soils are well known; however, our knowledge of the species that make up soil microbial communities remains incomplete. Nevertheless, the belief continues that soil biological phenomena of the type outlined by Waksman indicate soil fertility, one component of "soil quality."

In the last two decades, there has been a good deal of research on how different types of soil perturbation (chemical and physical) and rehabilitation/reclamation of soils affect various microbiological phenomena. The goal has been to determine which phenomena best indicate negative or positive effects on soil biota, so that they can be used as indicators of changing soil quality.

Thus Domsch et al. (1983), summarizing results from many studies of side-effects of agrochemicals on soil microorganisms, indicated that parameters tested were of widely varying sensitivity, as seen in the following examples:

- **High sensitivity:** populations of nitrifiers, *Rhizobium*, and actinomycetes; organic matter degradation rate; nitrification.
- **Medium sensitivity:** populations of algae, bacteria, and fungi; soil respiration (CO_2 evolution, oxygen uptake); denitrification; ammonification.
- **Low sensitivity:** populations of *Azotobacter*, microorganisms (general), and ammonifiers; aerobic N_2 fixing capacity.

At an international workshop on side effects of pesticides on soil microflora (Somerville et al., 1987), the following tests were recommended: litter decomposition (litter bags); nitrogen transformations (ammonification, nitrification, N_2 fixation); *Rhizobium*/legumes symbiosis (N_2 fixation, plant yield); Cyanobacterium.

Bengtsson and Torstensson (1988) published a detailed concept for a research program to evaluate how manmade substances affect soil biological variables. The general goal was to maintain, or even improve, soil quality in Sweden; the work includes reviews of approaches recommended by OECD and EPA.

Although these examples refer to the effects of pesticides, metals and acidification, they also are an attempt to use soil biological parameters as indicators of changing (deteriorating) soil quality. In studies on land reclamation, similar parameters can be used to assess soil rehabilitation (increasing soil quality). Zak et al. (in press) have reviewed the importance of soil microbial processes and dynamics in effective land reclamation. They concluded that although studies of microbial community structure may allow

inferences about the probability that reclamation will be successful, process studies, particularly the ratio of soil microbial respiration to total microbial biomass, provide the best indicators for overall (soil) system recovery.

Thus, there are diverse soil microbiological criteria that may indicate deteriorating or improving soil quality. These criteria may be tested at three levels: population level, community level, ecosystem level ("soil ecosystem"). We deal briefly with these levels in later sections. Our aim is to provide a brief overview of the merits of various types of soil microbiological parameters in monitoring soil quality. Therefore, there is no attempt to review in detail the large body of relevant published work, which spans the past seventy years or more.

Population Level Studies

This level studies the dynamics of presumptively or actually important individual species, or individual species that are sensitive to specific perturbations, that is, bioindicator species. Such studies involve determination of population densities, biomass, survival, and reproductive rates of the chosen species.

The importance of groups of species (communities) responsible for particular soil processes is well known, but the definition of individual species as indicators of soil quality is much more problematic. An exception to this comment may be individual species involved in nitrogen transformations, such as *Rhizobium* spp. (Domsch et al., 1983). Certainly, in agricultural and forest plantation soils, plant root pathogens may have profound effects on primary production. In these cases, knowledge of population size and inoculation potential, survival and competitive abilities of important species, combined with climate and soil data, can allow predictions of changing productivity of plant species.

Even if an individual microbial species can be defined as an indicator of soil quality, we must have specific, efficient methods for isolating that species and measuring its biomass. The use of selective isolation media and growth conditions is well known for such determinations (Page, ed., 1982), but more recently, fluorescence immunoassays followed by analyses by enzyme-linked immunosorbants and various molecular genetics approaches have provided powerful new tools for studying the autecology of a range of soil microorganisms (Paul and Clark, 1989; Parkinson and Coleman, 1991). Even if frequency of occurrence or a similar population characteristic of an individual microbial species is taken as an indicator of soil quality, data on such a characteristic frequently are difficult to interpret. This is because natural environmental factors can have important effects on the population dynamics of individual species. We consider this problem later.

Community Level Studies

These studies estimate species diversity and frequency of occurrence of species (bacteria and fungi). The literature is filled with examples of such synecological studies, which emphasize that there is high species diversity of microorganisms in soil with a wide range of functional attributes (Wicklow and Carroll, eds., 1981; Burns and Slater, eds. 1982).

Visser et al. (1984a) showed that drastic degradation of soil quality by surface mining decreased species diversity in soil microbial communities. This was attributed to loss of soil organic matter. Visser (1988) pointed out the importance of the relationships between microbial species diversity and functional diversity during land reclamation efforts using different organic amendments.

Zak et al. (in press) have reviewed approaches at the microbial (particularly fungal) community level to assessing the success of strategies to reclaim degraded land. They emphasized the importance of determining the stability of microbial communities in space and time, again with reference to function. They concluded that one can relate the probability of reclamation success to microbial community structure.

The foregoing comments relate to the special case of restoring drastically degraded soils. A more widespread phenomenon is the exposure of natural and agricultural soils to long-term human impacts. Here, microbial communities of high species diversity show changes whose speed depends on the level of the impacts. The high diversity of fungal species in agricultural soils has been reported by Domsch and Gams (1970). Domsch (1960) showed that a potential value of this diversity is that when the abundance of one group of fungi is depressed by pesticides, it is offset by increased abundance of other species. Fungicides affecting a wide range of fungi usually cause decreased soil respiration and decomposition rates of specific substrates for a short period (1 to 4 days) following application. After this, fungicide-tolerant fungi develop and cause soil respiration and substrate decomposition to recover (Domsch, 1968).

In all studies monitoring microbial communities in natural soils, or those undergoing drastic or chronic change from human activities, there are several basic problems that may limit the value of community level studies: we cannot accurately define the total microbial species complement of the soil under study (Parkinson and Coleman, 1991); fewer researchers can accurately identify species isolated from soil; although we have substantial data on the functional capacities of many species of soil microorganisms (e.g., Domsch et al., 1980, for fungi), it is difficult to relate data from laboratory studies on individual species' biochemical abilities to what they accomplish in soil (Swift, 1976); and accurate determination of the microbial species status of soil, and changes in that status, are laborious.

Thus microbial community studies, although of high ecological interest, should be undertaken only for good reason, that is, to answer specific questions. Obviously, studies of the total microbial community, or of the major groups of that community (bacteria or fungi), are fraught with methodological and interpretation problems, as we discuss later. Therefore, their value for monitoring soil quality changes is uncertain, except where soil quality has changed drastically.

However, studies of the communities of specific functional groups of the soil microbiota may have more significance in assessing and monitoring soil quality. For example, the community structures of species involved in the various phases of nitrogen transformations, including symbiotic N_2 fixation, and of mycorrhizal

fungi (VA- and ecto-) undoubtedly are indicators of the general quality of the soil.

Ecosystem (Soil Ecosystem) Level Studies

These studies center on the processes involved in cycling organic matter (carbon) and nutrients (mainly nitrogen), and on nutrient retention efficiencies. As stated earlier, since the early days of soil microbiology, various soil biological processes have been considered indexes of soil fertility. These approaches, many of which have been listed in the introduction, concern several major areas:

Carbon cycling

1. Organic matter decomposition rates. It is generally agreed that the rate of decay of natural litter is determined mainly by its physical and chemical qualities, and by temperature, moisture and the nature of the community of decomposer microorganisms and fauna (Swift et al., 1979). Therefore to monitor decomposer potential of soil as an indication of changing soil quality, field experiments using the well-known litter bag technique (for example, Bocock and Gilbert [1957] and many subsequent workers) seem inappropriate, because field moisture and temperature conditions vary greatly. Their variation from one experiment to another may cause decomposition rates to vary more rapidly than the variations caused by slowly changing soil quality.

Therefore, in a monitoring program, properly designed laboratory "mesocosms" (e.g., Taylor and Parkinson, 1988) are probably the best approach, using fresh soil samples, a standard natural litter, and constant temperature and moisture. Here, the only variable should be the possible changing decomposer potential of the decomposer community. CO_2 evolution or loss of litter mass can be used as the measure of decomposition. The same applies to monitoring the decomposition of a standard substrate, such as cellulose, lignin, or chitin.

2. Soil respiration (CO_2 efflux). Since the early studies of Waksman and Starkey (1924), attempts have been made to use soil respiration as an index of soil fertility. Details of field and laboratory measurements of CO_2 evolution from soils are given by Anderson (1982). However, field measurements of soil respiration have the same problem as litter decomposition: the potential "masking effects" of environmental conditions that change from one sample time to another.

Therefore, it appears that the most appropriate technique is a laboratory experiment where soil samples are held under constant temperature and water potential before and during CO_2 efflux measurements (Parkinson and Coleman, 1991). There have been many laboratory studies of the respiration (CO_2 efflux) of unamended soil samples, from which the amount of C evolved as CO_2 has been calculated. However, there have been very few attempts to relate these data to the actual microbial biomass in the soil samples. Therefore it often is difficult to interpret soil respiration data. We deal with this matter in the next section.

3. Microbial biomass carbon. Over the past 20 years, physiological methods have been developed to assess the total microbial biomass C in soil samples (e.g., fumigation incubation, fumigation extraction, substrate induced respiration). These methods are simple compared to the direct observation methods that have been in use for much longer (Parkinson and Coleman, 1991).

Of the physiological methods listed above, substrate induced respiration (SIR) appears to have the greatest potential for assessing and monitoring soil quality (Anderson and Domsch, 1978). SIR is the initial respiratory response of a soil sample to an optimal addition of glucose. From this, using a calibration factor derived from fumigation incubation studies (see Anderson and Domsch, 1978, for details), microbial biomass C in the soil sample can be calculated: SIR of 1 ml $CO2\ h^{-1}$ at 22°C corresponds to about 40 mg of microbial biomass C.

The SIR method is valuable in soil monitoring studies for two major reasons: it is quick and simple, and it provides more information on the state of the microbial biomass than just a biomass value. A disadvantage is that it requires an apparatus that measures CO_2 efflux from several replicate samples very frequently.

SIR has several advantages in soil monitoring studies:

- Basal respiration measurements can be followed by SIR measurements on the same soil samples. Therefore the amount of C evolved as CO_2 (C_{resp}) can be related to the amount of microbial biomass C (C_{micro}). From these data a metabolic quotient qCO_2 can be calculated (C_{resp}/C_{micro}). Anderson and Domsch (1986) suggested that this quotient is a kinetic parameter that is important in defining soil microbial activity more critically. In ecosystems under stress, the respiration/biomass ratio is expected to increase, while in systems under rehabilitation it will decrease (Odum, 1969; 1985). It also decreases with increasing soil maturity (Insam and Domsch, 1988; Insam and Hasselwandter, 1989).
- The respiratory response of the microorganisms in soil samples for 48 h following an optimal addition of glucose can give useful data for assessing various types of stress in soils. Visser et al. (1984b) and Visser and Parkinson (1989) showed that increasing stresses on soil, such as topsoil stockpiling and acidification, increase the time to achieve peak CO_2 efflux following addition of glucose. It has been suggested (Visser and Parkinson, 1989) that the time to achieve maximum respiratory response to the addition of glucose or other easily assimilable substrate is a sensitive parameter in assessing stress on soils.
- The ability to determine microbial biomass C quickly allows calculation of the contribution of this C component to the total C content of these soils (C_{org}). Anderson and Domsch (1986) found that in agricultural soils of known origin and history, such as long term experimental fields, the C_{org} content contained 2.3-4.0% C_{micro}. They hypothesized that soils showing different C_{micro}/C_{org} ratios would be either losing or accumulating C. Insam et al. (1989) showed that this ratio is influenced by climatic conditions, particularly precipitation and evaporation. Zak et al. (in press) suggest that

C_{micro}/C_{org} measurements are valuable for soil monitoring because like measurements of qCO_2, they integrate several key ecosystem functions.

Nitrogen cycling

Measurements of rates of ammonification, nitrification and nitrogen fixation have been suggested as important in assessing soil fertility and the effects of environmental disturbances on soil quality. Rate of ammonification has been considered a relatively insensitive parameter for these assessments because it involves a wide range of soil microorganisms (Somerville et al., 1987; Bengtsson and Torstensson, 1988). In contrast, nitrification has been considered far more sensitive to a range of environmental disturbances because only a few microbial species are involved (Somerville et al., 1987; Bengtsson and Torstensson, 1988).

In locations where pesticides or other chemicals are being used on legumes, these authors have recommended that any studies on nitrogen fixation be confined to symbiotic nitrogen fixation. Where rice is grown, they recommended studies on growth and nitrogen fixing ability of *Cyanobacterium* and *Azolla/Anabaena* symbiosis. Methods for measuring the various processes outlined above as important in monitoring soil quality are given in papers in Page (ed., 1982) and in Harrison et al. (eds., 1990).

Nutrient leaching from soil (soil core microcosms)

To get away from population and community level parameters for assessing various types of soil perturbation, O'Neill et al. (1977) suggested soil nutrient loss as "a sensitive holistic measure of ecological effects." In studies on the effects of toxic substances incorporated into soil cores or blocks in the laboratory, disturbance to nutrient cycling (increased nutrient leaching) was seen when no significant changes were recorded in soil populations or community parameters. Jackson et al. (1977) described a soil core microcosm method for assessing the effects of a pollutant (As) on soil processes. They showed that aqueous leaching of Ca and NO_3-N was significantly increased by soil pollution.

The use of cores of natural soils, seeded with a suitable plant species, has been suggested by several groups, such as the U.S. Environmental Protection Agency, as a test for the ecological effects of chemicals added to soil. Here, primary productivity and appearance of the plants, nutrient loss in leachates and fate of the added chemical are measured.

Soil enzymes

Microorganisms, plant roots and fauna all contribute to the complement of soil enzymes. These enzymes occur in a range of living and dead components of the soil (Skujins, 1978). Consequently, the suitability of enzyme assays for microbial activity and soil quality assessments is questionable. Dehydrogenase activity may be an exception, because its biochemical properties make it unlikely to be present in soil in a free, extracellular state (Skujins, 1978). The activity of this enzyme has been used regularly to provide information on general soil microbial activity since the work of Lenhard (1956).

Klein et al. (1985) and Zak et al. (in press) reviewed the values of soil enzyme studies in land reclamation research. The former group concluded that soil enzyme studies provide information on the relative biological quality of different soil materials. In contrast, the latter group believed that enzyme activity studies (as a single parameter measurement) cannot estimate the long-term stability of the soil.

Working with a range of agricultural soils, Beck (1984) assayed various enzymes (reductases and hydrolases) together with total microbial biomass. He found highly significant correlations among all the measured parameters, and suggested that an "overall index of soil microbial activity" could be derived from them. However, in discussing laboratory tests for assessing side effects of pesticides on soil microflora, Somerville et al. (1987) considered enzyme assays to be unsuitable, for two main reasons. First, the diversity of organisms from which enzymes originate and the diversity of their location in soil make it very difficult to quantify the contribution of each to catalysis of a particular substrate. Second, universally accepted methods are lacking.

Conclusion

Even from this brief account, which has omitted comment on many excellent studies, we see that widely differing methods have been considered as potentially valuable for studying soil quality. We believe that ecosystem (process) level studies offer the best possibilities for rapidly assessing changes in soil quality. Data from process studies will then allow decisions to be made on whether to proceed with population or community level studies and, if so, will allow them to be planned more precisely

Whatever approach is taken, decisions must be made regarding the relative merits of field and laboratory experiments. We favor the laboratory approach, used by many groups, for a reason given earlier: under natural environmental conditions, where changes in temperature and moisture sometimes are extreme, there will be corresponding changes in microbial populations and communities, and in the processes they cause (Domsch et al., 1983). Natural stresses such as drought and freezing commonly depress microbial activity by 50% or more. These changes will mask the smaller effects of human activities on soil microbial communities and processes.

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Farm Profiles Invited

For its new department on alternative agriculture profiles, the **AJAA** welcomes short articles describing farmers who have adopted interesting alternative practices. The articles should include five elements: a brief description of the farm; the problems that made the farmer look for an alternative approach and the reasons why the alternative seemed plausible; a summary of the basic principles behind the alternative (possibly in a sidebar if it interrupts the flow of text); a discussion of how well the alternative has worked; and a discussion of the applicability of the alternative for other farms. The length should be 1500 to 2000 words.

Submissions must be accompanied by a release, signed by the farmer, giving permission for this material to be published in the **American Journal of Alternative Agriculture**. Vol. 3, No. 4, of the **AJAA** has a further description of the department (page 188); or query the editor for further information. Send submissions to the Editor, AJAA, 9200 Edmonston Road, Suite 117, Greenbelt, MD 20770.

Three New Beneficial Insects Offer Non-Chemical Controls

The USDA has found three new beneficial insects that hold promise as non-chemical controls for scale and whiteflies, which are threats to fruit and ornamental crops. The two scale predators are beetles which reappear when scale becomes a problem; the whitefly predator is a tiny stingless wasp, which kills whitefly by parasitizing or direct feeding. The beetles were so successful in eliminating scale that the Agricultural Plant Health Inspection Service has funded a national project for biological control on euonymus scale.

Invertebrates as determinants and indicators of soil quality

Nigel E. Stork and Paul Eggleton

Abstract. Invertebrates are an integral part of soils and are important in determining the suitability of soils for the sustainable production of healthy crops or trees. We discuss the importance of the soil invertebrate fauna in relation to terrestrial habitats and global biodiversity as we understand it. We describe the role of the main invertebrate groups in soils, including earthworms, termites, springtails, and nematodes, and how they determine soil quality. Practical problems in dealing with the invertebrate fauna include sampling, taxonomy and availability of biological information on species. Various measures are available that use invertebrates to assess soil quality, each with its advantages and disadvantages. They include abundance, biomass, density, species richness, trophic/guild structure, food web structure, keystone species and ecosystem engineers. We propose the three most useful and practical of these as suitable to be combined with other biological (microbial) and non-biological (hydrological, physical, chemical) criteria into a single index of soil quality that might be used on a regional, if not international basis.

Keywords: biodiversity, soil invertebrates, species richness, keystone species, earthworms, springtails, nematodes, termites

Introduction

The soil is among the most complex habitat systems on the globe, yet its biological systems are poorly understood. It provides a living place for at least part of the life cycle of many animals, and the highly connective nature of foodwebs means that most, if not all, terrestrial organisms depend directly or indirectly on biological processes in the soil. Many small organisms, such as insects and other invertebrates, play a vital role in the production and maintenance of healthy soils, and therefore are key elements in the development of sustainable agriculture and forestry.

The central tenet of this paper is that invertebrates are an integral part of soil systems and that soil quality results at least in part from the interactions of soil with its biotic community. To many soil invertebrate biologists this will seem a truism, given the extensive literature on this subject (e.g., Fitter et al., 1985; Edwards et al., 1988; Spence, 1985; Eselbeis and Wichard, 1987). To other biologists, however, and to most non-biologists, it is not so obvious. We review the ways in which invertebrates determine the nature of soil, and show how invertebrates can be used to assess human-induced changes in soil quality. We define "soil quality" as "the fitness of soils for the sustainable production of healthy, agriculturally important plants." This paper outlines the role of invertebrates in soil processes, suggesting how this role might be included in a general index of soil quality. This index would include physical and chemical measures, as well as other biological measures such as microbial activity. Consequently, we first outline the contribution of the soil fauna to biodiversity in general, emphasizing invertebrates. Second, we discuss the importance of the soil fauna in relation to the fauna of other terrestrial and aquatic ecosystems. Third, we describe the most important invertebrate components and their role in soil processes. Fourth, we discuss problems of sampling, identification, and geographical distribution. Fifth, we consider how different measures of invertebrate biodiversity (biomass and abundance; species richness) and ecological complexity (trophic group analysis; food web studies; recognition of keystone species/ecosystem engineers) have been or could be used to indicate management-induced changes in soil quality. Finally, we suggest which of these measures are most practical. Because the field we cover is wide, we take a conceptual view and suggest broad approaches based on ecological and systematic theory.

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Invertebrate Diversity—the Baseline

Only a fraction of the species on earth have been named, but what fraction is a matter of great debate. We are not even sure how many species have been named already, although estimates range from 1.4 to 1.8 million (Stork, 1988; Stork and Gaston, 1990; May, 1990a,b). Insects comprise the largest single group of named species and attention has therefore focused on this group for estimates of total number of species on earth. Until the 1980s, most estimates for the number of insect species were between 1 and 3 million. Against this baseline, the 30 million tropical species suggested by Erwin (1982) created considerable renewed controversy. His method of estimating this figure, and the assumptions and extrapolation involved have been questioned by several authors. More recent estimates have been below 10 million (Stork, 1988; May, 1990a,b; Thomas, 1990; Gaston, 1991; Holloway and Stork, 1991; Hodkinson and Casson, 1991). Less

n has been paid to global estimates
r diverse groups of organisms, al-
Hawksworth (1991) suggests that
ay be 1.5 million species of fungi.
oup whose size is completely un-
are nematodes. Although fewer
)00 species have been described,
a sediments and terrestrial samples
. that the diversity of nematodes
equal or surpass that of insects (J. Lambshead, personal communication). In practice, species concepts for nematodes are far from clear.

Although we have no clear idea of global invertebrate diversity, we know more about their general patterns of distribution. Most diversity at the species level is found in terrestrial environments and greatest diversity occurs in the 5 to 7% of land covered by tropical forests. The indications are that for every temperate species there could be at least 5 to 10 tropical species, although a few groups show the reverse trend. At the regional or local level there are few data on the turnover of species in soil with distance, altitude and habitat, particularly for tropical soils.

The significance of the soil fauna is seldom recognized. In one study of lowland rain forest in Seram, Indonesia, there were more individuals and greater biomass of invertebrates in the top few centimeters of soil and leaf litter than in the canopy (Stork and Brendell, in press; Holloway and Stork, 1991). One of several assumptions that Erwin (1982) made in deriving his global estimate of 30 million species of tropical insects was that two-thirds of insect species are associated with the canopy of trees. Evidence from an intensive study of the beetle fauna (over 6000 species) of all habitats in one area of Indonesian rain forest suggests that this assumption is heavily biased toward the canopy and that most insects are ground based (P. M. Hammond, N.E. Stork, and M.J.D. Brendell, unpublished). Hammond (1990) found that 25% of this beetle fauna was associated with the soil/leaf litter for the major (feeding) part of their life cycle. Of the British insect fauna, arguably the best known in the world, probably 10% of the 22,000 species are closely associated with the soil and leaf litter, and possibly another 15% are loosely associated (e.g., many Lepidoptera pupate in the soil).

Clearly, the soil is very important for biodiversity. How vital that biodiversity is to the stable functioning of soils is unclear (see Castri and Younes, 1990, and below).

Invertebrates in the Soil

In this section we briefly discuss the kinds of invertebrates found in the soil, highlighting those that make the greatest contribution to soil quality and describing what is known of their role in soil processes. One classification into three groups derives from their size and the way they interact with their habitats (Anderson, 1988a).

- *Microfauna.* These are invertebrates of less than 100 μm, mostly nematodes (along with Protozoa, which are outside the scope of this paper). Nematodes are associated with water films (2 to 5 μm thick) on the surface of soil and organic particles, and water filled pores (20 μm wide).
- *Mesofauna.* This diverse group of invertebrates are of sufficient size to overcome the surface tension of water on soil particles but are not large enough to disrupt the soil structure in their movement through soil pores (body width between 100 μm and 2 mm). They include Acari (mites), Collembola (springtails), enchytraeid worms, small Diplopoda (millipedes), and many small larval and adult insects. Studies of the mesofauna have concentrated on springtails and mites. Many species of mesofauna are mycophagous and therefore affect fungal populations strongly.
- *Macrofauna.* This group consists of species large enough to disrupt the soil by their burrowing and feeding (2 mm to 20 mm wide). The most important taxa are Isopoda (woodlice), larger Diplopoda, earthworms, Isoptera (termites), Coleoptera (beetles), Diptera (flies), ants, and molluscs.

All three faunal types have a complex role in soil processes. In general, the micro- and mesofaunas appear to enhance microbial activity (Wright et al., 1989) and to accelerate decomposition (Christiansen et al., 1989; Setala et al., 1988), as well as mediating transport processes in the soil (Anderson, 1988b).

Springtails, earthworms, nematodes, and termites, are especially important in soil processes. Below, we summarize their contribution.

Springtails

Soil-dwelling springtails decompose plant residues (Kiss and Jager, 1987; Takeda, 1988). Larger species increase mineralization by selective feeding on fungi, while smaller species help in soil humification by non-selective scavenging and by mixing organic material and mineral soil particles (van Amelsvoort et al., 1988). However, grazing by some species may reduce VAM fungi (Rabatin and Stinner, 1988), and selective grazing by springtails certainly seems to affect the growth of certain litter-decomposing fungi (Newell, 1984a,b). Low levels of Collembola stimulate both fungal and bacterial growth, but higher levels may negatively affect fungal populations and reduce humification of the soil (Hanlon and Anderson, 1979).

Earthworms

The role of earthworms in soil turnover has long been recognized (Darwin, 1881; Lee, 1985). Up to 50% of aggregates in European soils may be weathered earthworm casts (Rushton, 1988), and soils worked by earthworms have higher pore volume, increased field water holding capacity, more water stable aggregates and higher infiltration rates than soils without earthworms or only with species active on the surface (Lee, 1983).

Adding earthworms to the soil can increase agricultural yields, at least in the temperate region (Rushton, 1988). Improved soil structure results from tunnelling and casting (Dexter, 1978). Tunnelling increases the air space in the soil, reducing erosion because of higher infiltration rates. This is important in the tropics, where high intensity rainfall causes heavy runoff (Aina, 1984). Surface casting promotes soil mixing. Earthworm casts increase the overall aggregate stability of the soil (Hopp and Hopkins, 1946; Blanchart et al., 1989). Where earthworms are not present, dense

mats of dead or decaying root material can build up at the soil surface, locking up nutrients. Earthworms also reduce soil crushing after heavy rainfall (Kladivko et al., 1986).

Earthworms are important in making phosphorus (Sharpley and Syers, 1976; Mackay et al., 1982), nitrogen (Svensson et al., 1986; Syers et al., 1979) and other nutrients available in the soil, while enhancing microbial activity within the cast material. They also may make the soil more suitable for springtails and other non-burrowing invertebrates by increasing the abundance of vertical pores (Marinissen and Bok, 1988). In the tropics megascolecid earthworms may significantly reduce the rate of decomposition of organic matter after clear felling of savannas and their subsequent cultivation. This may be important in reducing humus loss in cultivated land (Martin, 1991).

Nematodes

Little is known of soil nematodes, largely because of their microscopic size, clumped distribution, and trophic variation (Freckman, 1982; Yeates, 1987). Phytophagous nematodes often reduce plant primary production. However, the situation is not simple. Feeding by plant parasitic nematodes reduces crop yields (Sykes, 1979), yet lower levels of activity may stimulate plant growth (Jones, 1957).

Often there is a positive correlation between total nematode abundance and primary productivity (or other correlates of primary productivity, such as levels of available phosphorus). Studies of plant growth suggest there is increased nitrogen mineralization in nematode grazed microcosms when the C:N ratio is low (Elliott et al., 1980; Yeates and Coleman, 1982). Soil nematodes may enhance decomposition by 16% in field soil and up to 30% in litter (Pradhan et al., 1988).

Microcosmal studies of the effects of manipulating populations of a few soil species suggest that fungal and bacterial feeding nematodes may stimulate microbial populations at low densities (Griffiths, 1986), but inhibit them at high densities. Such high densities of microbe feeding nematodes may be obtained after the application of insecticides that remove nematophagous mites. Manipulation experiments have shown up to 40% reduction in decomposition in plots from which mites have been excluded in a desert ecosystem (Santos et al., 1981). This is thought to be due to a lack of predator pressure on cephalobid nematodes, which are bacterial grazers. With reduced mite predation, bacterial grazers may reduce populations of bacteria to a level where nutrients become immobilized in the soil. The same does not seem to apply to fungal feeding nematodes, which increase in abundance immediately after mite removal, but return rapidly to premanipulation levels. However, bacterial feeding nematodes may enhance nitrogen mineralization more effectively than fungal feeders, because fungi are efficient nitrogen mineralizers themselves, and this does not appear to be greatly enhanced by nematode grazing (Ingham et al., 1985). Bacterial feeding nematodes may be most effective in synergy with soil protozoa (Griffiths, 1986, 1989).

An important feature of nematodes is that they can enter cryptobiotic states and thus track temporal changes in microbial levels. Nematode populations are affected by soil structure. Population growth is lower in fine textured soil than in coarse textured soil (Elliott et al., 1980).

Termites

Termites are a tropical/subtropical group of social insects occurring below 45° latitude. Often they are the dominant group by far in arid or semi-arid soils. Because some species can form vast colonies of millions of individuals, their effects on the soil can be considerable (Nye, 1955; Lee and Wood, 1971; Lobry de Bruyn and Conacher, 1990). Wood (1988) categorizes the main ways in which the soil is modified by termites as: physical disturbance of soil profiles; changes in soil texture; changes in the nature and distribution of organic matter; changes in the distribution of plant nutrients and hence changes in soil fertility; and construction of subterranean galleries. The importance of fungus-growing termites on litter turnover, soil fertility and global carbon cycling is only just beginning to be considered (Jones, 1990).

The construction of the sometimes huge nest and gallery systems by termites involves considerable movement of soil and litter (Collins, 1983). These structures are made of termite feces, saliva, and soil particles in a particular size range. Thus they may radically alter the texture and structure of the soil. Over long periods, large amounts of soil may be deposited on the surface and subsequently eroded (Bagine, 1984). Nutrient levels in soils can be altered by termites, particularly those species that forage for food and use symbiotic microfauna and microflora to break down plant materials (Collins, 1981; Coventry et al., 1988). Termites may concentrate organic nitrogen and carbon in their nests (Laker et al., 1984). The construction of subterranean galleries affects the soil water regime, increasing porosity, aeration and water infiltration. In one study in New Mexico, low vegetation cover areas treated with insecticide had significantly lower infiltration rates than untreated areas (Elkins et al., 1986), suggesting that subterranean galleries of termites enhance water infiltration and retention of topsoil.

Other invertebrates

Although not considered in detail in this paper, holometabolous insect groups such as Coleoptera (beetles) and Diptera (flies) are important in soils. Usually these are the groups with the greatest species richness but not always the greatest abundance or biomass. Many predatory and parasitoid soil insect groups are vital in the control of root feeding pest invertebrates (Clausen, 1940). Insects such as beetles and flies are particularly important in the breakdown of dung, carrion and leaf litter, and therefore return nutrients to the soil. Scarabaeid beetles may be especially important in this role (Greenslade, 1985; Kalisz and Stone, 1984).

Ants are found in most terrestrial habitats. Most are predators, and as such are a critical component of aboveground and soil communities. Ants, like termites, are social insects and their colonies have similar, but usually less spectacular, effects on the environment (Nye, 1955; Lobry de Bruyn and Conacher, 1990; Rogers and Lavigne, 1974). Many studies have shown the positive and negative impacts of ants

on different feeding groups of herbivorous insects and the close relationship that some plants have with particular species of ants. Less well known is the importance of ants in regulating the populations of other soil invertebrates.

Mites are important in the soil as fungivores, bacteriovores and nematode predators (Largerlof and Andren, 1988). Generalist fungivore mites may be important in nutrient mineralization from decaying roots (Arnold and Potter, 1987). They also are important in fragmenting litter, dispersing microbial spores, and stimulating microfloral activity.

Of non-insect groups, both Isopoda and Diplopoda are important as vectors of vesicular arbuscular mycorrhizal (VAM) fungi (Rabatin and Stinner, 1988). Isopods also may move litter deeper into the soil (Hassell et al., 1987).

Perhaps the most important contribution of invertebrates to soil structure is their feces. The fine structure of soils, and therefore many of its structural features that contribute to soil fertility, is largely determined directly (topsoil) or indirectly (mineral soil) by invertebrate fecal dynamics (see papers in the symposium volume edited by Spence, 1985; especially Pawluk, 1985; Rusek, 1985). For example, invertebrate fecal material was a significant component of all surface layers rich in organic matter in all regions of Canada (Pawluk, 1987). Decaying invertebrates may also contribute to nitrogen mineralization of the soil (Abrahamsen, 1990).

Problems in Studying Soil Invertebrates

Sampling and extraction

Sampling procedures are critical when assessing the abundance, biomass and species richness of invertebrates. Basic techniques have been described by Southwood (1978) and a good review of techniques applied to soil invertebrates is given by Edwards (1991). Different invertebrate groups usually require very different methods of sampling. This can cause problems when comparing quantitative data collected in different ways (Schaefer and Schauermann, 1990). For example, the abundance and biomass of termites are usually assessed by digging and hand sorting, while nematodes are extracted by very small soil core samples. Similarly, different research workers looking at the same invertebrate groups often fail to standardize their sampling protocols. A common source of error is variation in the depth and number of soil cores. Poor experimental design can lead to underestimation or even overestimation of groups that have patchy distributions.

Various extraction techniques are used to recover soil invertebrates. Most of these involve the movement of the animals through the soil, usually along behavioral gradients such as heat, light or chemicals (e.g., Tullgren-Berlese/ Kempson funnels). Others involve washing the animals from soil (e.g., Macfadyen apparatus). None of these techniques extract all the soil fauna, and some sample one group better than others. These problems have led to considerable variation in estimates of the numbers and biomass of soil invertebrates. Extraction techniques that drive living invertebrates through the soil are successful only when the temperature/light gradient is carefully controlled. The modified Kempson extraction process as used by Adis (1987), for example, takes 10 to 12 days. As a result, his estimates of arthropod abundance in rain forest soils in Brazil (Adis, 1988) are greater than those using more rapid methods of extraction (e.g., Stork and Brendell, in press).

Because of the problems of extracting the smallest invertebrates, (and perhaps because workers have fallen into the trap of believing that smaller means less significant), many authors have considered only the abundance of the macro and occasionally the mesofauna (e.g., Collins, 1980; Leakey and Proctor, 1987). The omission of the most abundant arthropod groups from abundance analyses may have serious consequences, particularly if such results are used to examine resource utilization and decomposition processes. In addition, data from larger arthropods often are difficult to interpret, because these groups are found at lower densities and their characteristics have higher standard errors than for smaller arthropods.

Taxonomy and ecology

Most soil faunas still are largely undescribed for most places on earth. This is particularly true of tropical sites. However, most invertebrate groups are well known and not difficult to separate. The difficulties usually lie at the species end of the scale. Indeed, many important groups, especially termites and nematodes, are taxonomically intractable (Greenslade, 1985). Taxonomists, an increasingly rare resource, too often produce keys that are designed for use by other taxonomists rather than by other biologists. The development of simple interactive computer identification systems, such as CABIKEY (CAB International, unpublished); PANKEY (Pankhurst, 1986, 1988); or COMTESA (Moldenke et al., 1991) should help reduce these problems and allow non- specialists to identify their own soil faunas. There is little ecological information for many species and accurate assessments are impossible in tropical regions, where a large part of the soil fauna may comprise species unknown to science.

Distributional factors

The distribution of invertebrate groups varies considerably around the globe. Abiotic factors, latitude, and altitude are the most important influences on the composition and trophic structure of the soil fauna. Disturbance by humans also is important, although changes through disturbance often mimics those caused by natural processes. For example, plowing dries out the soil, making it less habitable for several hydrophilic groups, such as earthworms and nematodes (see below).

Abiotic factors clearly are important, especially extremes of humidity and temperature. Nematodes become inactive below soil water matric potentials of -0.4 MPa (Freckman et al., 1987), and earthworms probably require even higher water potentials. In the driest soils, only fungi and fungivorous mites appear to survive;

desert soil ecosystems may contain only these organisms for long periods (Whitford, 1989). The ability of mites to assume cryptobiotic states at low water matric potentials may explain this. Soil temperatures of 40C and above are regularly attained in arid and semi-arid tropical and subtropical zones, and few animals other than some mites can withstand such temperatures (Whitford, 1989; Abdel-Galil and Darwish, 1987).

Differences in latitudinal diversity gradients for some groups, such as termites and earthworms, are reflected at least in food web structure if not trophic structure, with termites dominant in the tropics and earthworms in many temperate regions. Latitudinal gradients have been considered widely for many terrestrial and marine ecosystems but relatively rarely for soils (for a review of such studies see Petersen and Luxton, 1982). In many ways this is surprising given the low dispersal ability of many soil organisms and therefore their potential to be strongly constrained by historical biogeographical factors. How latitudinal gradients in soil taxa might change the nature and magnitude of soil processes mediated by invertebrates is unknown. However, there are hints that they could be extremely important (for example, the effect of earthworms introduced to New Zealand, O'Brien and Stout, 1978; see below). The major clades of some soil taxa may be found in very different parts of the world. Low-vagility groups such as earthworms are obvious examples. None of the five families of closely related holarctic earthworms are native to any other biogeographical region (Sims, 1982), although they have been dispersed by humans all over the world.

Altitude also constrains invertebrate populations. Leakey and Proctor (1987) showed that in Borneo the proportional biomass of annelids and diplopods dropped from lowland to upper montane forest, while rising for arachnids and cockroaches. On Volcan Barva in Costa Rica, some groups (Oligochaeta and adult Coleoptera) in soil and leaf litter decreased in biomass and density with increased altitude while others (Gastropoda, Araneae, Diplopoda, Symphyla, Dermaptera and larval Diptera) increased (Atkin and Proctor, 1988). Similar increases were found for Oligochaeta, Isoptera and Chilopod on the slopes of Gunung Janing Barat (Brunei) while ants were most abundant and had highest biomass at a mid-altitude site.

Invertebrate Measures of Change in Soil Quality

The preceding sections demonstrate that invertebrates are not just passive inhabitants of the soil, but are active and integral constituents of soil systems. Their presence alters the physical and chemical structure of the soil and the rate and extent of soil processes. They are vital in determining soil quality for the production of healthy crops or forests, although the extent of this has been questioned (Anderson, 1987; Wright and Coleman, 1988). Soils that have poor hydrological, physical or chemical properties will inevitably have poor invertebrate communities. Many workers have used assessments of invertebrate communities to examine soil quality and the effect of human-induced changes such as deforestation or plowing. The loss of particular species may seem to have no direct impact on soil quality, but it may severely affect those species with more direct roles through food web interactions (see below). We must understand the structure of whole soil communities and how they are affected by different management practices. But how practical is the elucidation of such communities, and can we get the information we require from simple, easily sampled parameters? In this section we review various parameters, stressing both their theoretical power to explain soil invertebrate processes and their practicability.

Biomass, density and abundance

Most invertebrate studies of management-induced changes in soil quality have measured biomass, density or abundance of invertebrates. Some general tendencies can be identified.

Soil fauna biomass often drops with increased agricultural usage in pastures and arable land. For example, earthworm populations drop significantly under plowing (Edwards and Lofty, 1982; Christensen et al., 1987; Rushton, 1988; Garceau et al., 1988; Cavalli, 1989). Nakamura (1988) showed that direct drilling and rotary digging reduced the abundance of Enchytraeidae (Annelida), oribatid and other mites, springtails and other invertebrates in a Japanese arable andosol, while the application of an organic mulch increased it. Stinner et al. (1988) showed that under no-tilled treatments, the abundance of mites and springtails was higher than with conventional plowing. Studies in North Dakota also showed a higher abundance of springtails in no-tilled versus tilled soils, but the effect on mites was the opposite (Boles and Oseto, 1987). Compaction of soils by tractors also reduces invertebrate biomass and abundance (Aritajat et al., 1977).

High maintenance conditions (fertilizer, herbicide and insecticide treatments) result in greater abundance and biomass of invertebrates. For example, the abundance of oribatid mites on Kentucky bluegrass turf increases under high maintenance conditions (Arnold and Potter, 1987) and mites, springtails, isopods and diplopods also were more abundant after the application of lime fertilizer and organic manure in Brazil (Luizao, 1985). Reclaimed sites tend to show rapid increases in invertebrate biomass and abundance (e.g., Hutson, 1980).

Woodland areas tend to support a higher biomass of soil invertebrates than grassland. In a *Fraxinus americana* plantation in Quebec, the population density of edaphic mites, springtails, insects and other soil arthropods dropped under tillage and harrowing (Tousignant et al., 1988). The average abundance of mites and insects decreased by half, and that of springtails was reduced by 88%. This may be correlated with a drop in the humidity of the soils. Another study on mixed forest in Ontario showed that both whole tree and conventional harvesting reduced the arthropod fauna considerably. Oribatei, Prostigmata and Mesostigmata were found in significantly greater numbers in uncut plots than harvested plots. Whole tree harvesting has less effect on soil arthropods than conventional tree harvesting (Bird and Chatarpaul, 1986). Earthworm numbers also drop on deforested land (Krishnamoorthy, 1985; Dunger, 1988), although in some temperate coniferous forests,

earthworms may be absent (Shaw et al., 1991). Similar depression of invertebrate abundance and biomass occurs in felled and cultivated tropical forests (Lasebikan, 1975; Critchley et al., 1979; Badejo and Lasebikan, 1988; Dangerfield, 1990) and subtropical forests (Abe and Watanabe, 1983).

Correlation between the abundance of invertebrates and various soil factors has often been used to indicate differences in soil quality. Van Straalen et al. (1988), for example, showed that the abundance of oribatid mites and sminthurid springtails decreased in Dutch coniferous forests as the C:N ratio increased and the Mn concentration decreased. Similarly, a positive correlation was found between the mite *Tetranychus curcubitacearum* and nitrogen levels in a field in Egypt (Hoda et al., 1986). Springtail and mite densities often are positively correlated with humidity and negatively correlated with temperature (Jam et al., 1986; Hutson and Veitch, 1987). Pollutants at sub-lethal levels can change springtail species composition (Bengtsson and Rundgren, 1988). Finally, there are clear physical and chemical influences on earthworm distribution (Lavelle, 1988a). Calvin and Diaz-Cosin (1985, 1986) show the influence of pH, soil texture and C:N ratio on earthworm abundance.

Total abundance, biomass and density represent simple variables that can be measured independent of the difficulties involved in recognizing factors at the species or microsite level (Anderson et al., 1985). However, these measures can be variable and represent "snapshots" in time. Although seasonal changes in abundance and biomass can be considerable, for invertebrates these parameters do not fluctuate as rapidly and as dramatically under minor changes in soil temperature or moisture content as they do for microorganisms such as bacteria and fungi. These measures, however, tell us little about community structure and nothing about the likely course of future soil processes. King et al. (1985), for example, compared springtail populations in natural and improved pastures in Australia and showed that although abundance rose under improved pasture, the overall species richness dropped. In addition, species composition changed, with many more introduced than endemic springtail species present in the improved pasture. Clearly, abundance measures can be misleading about invertebrate-mediated soil processes. So, is species richness better for this purpose?

Species richness

Species richness has been used in many soil studies. For example, the number of species of earthworms fell from eight to three in a Canadian deciduous forest after tree felling and plowing (Garceau et al., 1988). Similar results have been found for earthworms in woodland and grasslands in India (Krishnamoorthy, 1985), for earthworms and termites in primary forest converted to improved pasture in Peru (Lavelle, 1988b), and for mites and Collembola in primary and burnt secondary forest in central Amazonia (Adis, 1988). In addition, mite and collembola species richness change with pH (Hagvar, 1987). Occasionally, some groups become more species rich in poorer soils. Braithwaite et al. (1988), for example, found that species richness for termites rose when various measures of soil quality declined in Kakadu National Park, Australia. This may be due to the absence of competitors in poor soils, so that termite species richness increases as the overall community is impoverished.

An advantage of species richness is that it provides a broad measure of the complexity of communities and perhaps their resilience to change. Its disadvantage lies in the practical difficulty of distinguishing invertebrate species and the little that it reveals about species interactions. However, species richness has the potential to tell us more about invertebrate communities and soil quality than straight biomass, density or abundance. The following approaches go beyond simple taxonomic biodiversity measures and attempt to get at ecological complexity and interactions directly.

Trophic group diversity

A simple ecological classification of soil trophic structure reflects the common resources that different species use: primary producers (green plants), herbivores, predators and decomposers. Although many studies of soil invertebrates examine biomass, abundance, or species richness, few take into account the trophic arrangement of soil communities. In practice, trophic analysis of the soil fauna is very difficult because it requires knowledge of the biology of individual species or groups of similar species. It is not enough to show changes in species richness of taxa chosen at high taxonomic levels if such levels embrace species with a wide range of trophic responses to differing soil conditions. Nematodes, for example, input into soil processes at almost every trophic level. Some workers have argued that studies of particular taxonomic groups tells us very little, because of the convergence in trophic function of phylogenetically unrelated organisms and the divergence in trophic behavior of related taxa (e.g., Walter et al., 1988 for predatory soil arthropods). However, this has not been proven or examined for most groups, and taxonomy may be a useful predictor of ecological function if the right taxonomic levels are chosen for investigation (Gauld, 1986).

Despite these problems, trophic group structure is increasingly analyzed in impact assessments of management practices on soil communities. A particularly useful method is to examine groups of species that use the same trophic level resource but in different ways. These have been termed functional groups or guilds (see also, in the context of soil guilds, the "league" concept of Faber [1991]). A few examples are given below.

The number of earthworm guilds (functional groups) fell from four in tropical forest to one in cultivated land in Peru (Lavelle, 1988a,b). In the temperate region, plowing buries leaf litter and sward, thus removing the food of one guild of earthworms (those that form permanent burrows and forage on the surface), and destroying the habitat of another (those that live in the leaf litter and sward). A third guild (those that live and feed entirely within the soil) increase in biomass and abundance (Rushton, 1988).

Several authors have shown that the composition of nematode guilds differs according to the nature of soil in which they are found (Ingham et al., 1989; Boag,

1988; Arpin et al., 1986). For example, Arpin and Ponge (1986) show how guild structure changes between a *Pinus sylvestris* plantation and a mixed *P. sylvestris* and *Quercus petrae* plantation, because of less disturbance in the mixed woodland. Braithwaite et al. (1988) demonstrated considerable variation in the number of species of different guilds of termites and related this to soil quality and other factors (see above).

An interesting aspect of trophic group studies is the uncertain effect that pesticides, which are intended to kill specific taxonomic groups, have on community structure. A nematicide kills nematodes regardless of their trophic position and disrupts the whole community if functional redundancy is low (discussed shortly). Insecticide treatment of a maize system led to increased oribatid mite density but consistently lowered mesostigmatid mite density, with uncertain community consequences (Stinner et al., 1988).

Trophic studies show that some systems recover slowly from depauperation, if at all. Studies of beetle assemblages in Wyoming (Parmenter and MacMahon, 1987) suggest that the difference in trophic structure between undisturbed and reclaimed soil sites are so great that the original trophic structure might take many years to return.

Of fundamental importance both to studies of species richness and to trophic analysis is the concept of "functional redundancy." How far can a community be reduced before it begins to lose its trophic cohesion? How many units (i.e., species) can a system lose before trophic groups are lost, harming soil quality? What is the minimum number of species required for the soil community to survive as a significant contributor to soil quality? How well can stressed communities regenerate? We need to answer these questions before the connection between biodiversity and soil quality can be adequately assessed.

Food webs

Conventional trophic analysis takes a simplistic view of species interactions (for understandable pragmatic reasons). In reality, species of organisms are linked in webs of interactions that can be extremely complex. Many such food webs have been studied and described, particularly those for simple, species-poor systems such as treehole communities (Pimm et al., 1991). Few food webs have been constructed for soil communities. However, conceptual models have been proposed. For example, Hendrix et al. (1986) drew diagrams of possible food webs associated with tillage and non-tillage systems. They suggested that tilled systems are dominated by disturbance- adapted bacteria with high metabolic rates, while non-tilled systems are dominated by fungi. The structure of these food webs suggests that decomposition is faster in the tilled system and that nutrient loss from the soil therefore is greater. Food web structure is important because the rate at which populations recover from disasters may well be dependent on food chain length (Pimm, 1982). Removal of individual species from food webs is likely to have unpredictable effects depending on the position they occupy and the number and abundance of dependent organisms. Long term studies are required to understand the effects of changes in food web structure.

Keystone species and ecosystem engineers

The idea that some species are more important for the structure of communities than other species (or groups of species) has attracted some support (Paine, 1969). These "keystone" species usually are very abundant or of considerable biomass (e.g., oak trees in an oak woodland). Alternatively, if they are small or less abundant, they play a critical role in a food web (e.g., euglossine bees and brazil nut trees). However, occurrence of keystone species is uncertain outside aquatic ecosystems (Krebs, 1985) and there seems no easy way to identify possible keystone species in the very complex soil environment.

A related and perhaps more useful idea is that of "ecosystem engineers" (C.G. Johns and J.H. Lawton, unpublished manuscript). Certain groups of organisms, sometimes even single species, may "engineer" environments for many other organisms and thus form the bedrock of communities. In soil, groups that might be considered ecosystem engineers are earthworms (predominantly in temperate regions), termites and ants (predominantly in tropical regions).

In temperate regions, earthworms make a major contribution to soil structure, and thus to soil community stability and soil quality. The introduction of earthworms to New Zealand (Stockdill, 1982) appears to have increased the annual flux of C from 300 to 1000 kg ha^{-1}, while mean residence time of organic compounds has decreased from 180 to 76 years (O'Brien and Stout, 1978).

Certain species of termites have been identified as potential keystone species (Redford, 1984). Termitaria have a higher nutrient content than the surrounding soil, and provide habitats for many other organisms, even when the termites have abandoned them (Salick et al., 1983).

International Measures of Soil Quality-Ranking Parameters

The need for a global assessment of land degradation, highlighted by the UN conference on the Human Environment, was acted upon by the Food and Agriculture Organization, which established an international set of standards of soil types. This paper was presented at a meeting on the Assessment and Monitoring of Soil Quality convened to investigate the possibility of establishing some simple measures of assessing soil quality. Several physical, chemical and biological factors contribute to the quality of soils and ultimately to the nutritional value of crops. Measurement and monitoring of soil quality therefore has to take these factors into account. A simple index of soil quality might include three invertebrate measures as well as two or three each of hydrological, chemical, physical and microbiological characteristics of the soil. Of the various biological criteria that have been discussed above, those that are selected must reflect the nature of the particular soil in question and the region. Earthworms may be a key group for temperate regions, but termites may be more appropriate for drier tropical or subtropical soils. (Note, however, that earthworms can be very important in wet tropical soils, e.g., Aina, [1984].) These criteria also must be easy and cheap to determine. We have discussed how

ecological factors must be taken into account through consideration of trophic, guild, or food web structure. We suggest the following as a priority list of measurable biological criteria for invertebrates:

1. Keystone species or ecosystem engineers. Where such groups can be identified unambiguously, their abundance, biomass and density may represent the best criteria for quickly and effectively assessing the invertebrate contribution to soil quality.

2. Taxonomic diversity at the group level. Assessment of the abundance, biomass and density of all soil invertebrates at the order/class level will provide a simple indication of the ecological complexity of the soil community.

3. Species richness of several dominant and perhaps more taxonomically tractable groups of invertebrates. Again, this will indicate the ecological complexity of the soil community.

Inevitably, these three measures will provide only a simple guide to soil quality. We echo the conclusion of Anderson (1988a) that the real obstacle to evaluating the invertebrate contribution to soil quality is a "lack of understanding of the links between gross soil processes and the structure of soil organism communities." If we are to understand these processes, then at least one or two major, in-depth studies of the community structure (e.g., Schaefer and Schauermann, 1990) and of the interactions of invertebrates with each other and with micro organisms and their soil environment must be attempted.

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Soil and crop management effects on soil quality indicators

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Abstract. *People are becoming more aware that our soil resources are as vulnerable to degradation as air or water, but criteria are needed to learn how soil quality is changing. Our objectives in this review are: (1) to illustrate that interactions between human and natural factors determine soil quality; (2) to identify indicators that can be used to evaluate human-induced effects on soil quality; and (3) to suggest soil and crop management strategies that will sustain or improve soil quality. The physical, chemical, and biological processes and interactions within the soil are critical factors affecting all indicators of soil quality. The biological processes are especially important because they provide much of the resiliency or buffering capacity to ameliorate stress. Presumably, no single soil or crop management practice will guarantee improved soil quality, but conservation tillage, cover crops, and crop rotations are practices that may be effective. Alley or narrow-strip cropping may facilitate adoption of several of those agronomic practices and increase temporal and spatial diversity across the landscape. To maintain or possibly improve soil quality and simultaneously address a growing waste disposal problem, we suggest that urban lawn and newspaper waste be evaluated as carbon sources. We conclude that the most critical factor, regardless of the soil and crop management strategy, is to recognize that carbon is an essential element for improving soil quality in the U.S. and around the world.*

Key words: Soil tilth, conservation tillage, cover crops, crop rotations

Introduction

Soil quality can be defined as the ability of the soil to serve as a natural medium for the growth of plants that sustain human and animal life. Interactions among the five basic soil forming factors (Jenny, 1941)—parent material, climate (including water and temperature effects), macro- and micro-organisms, topography and time—create an inherent and relatively stable soil quality that has distinctive physical, chemical, and biological characteristics in response to prevailing natural factors. A sixth soil forming factor, occasionally included in the basic model for describing a soil (Soil Science Society of America, 1987), is humankind. Human actions quickly can affect several natural factors and thus determine whether inherent soil quality will be lowered, sustained, or improved over relatively short intervals.

Natural factors influencing soil quality include parent material (mineral content, particle size, etc.), which influences fertility, chemical reaction, and soil texture; depositional method (residual, or transported by ice, water, or wind), which primarily affects soil texture and landscape topography; and climatic patterns, including precipitation, temperature, and the amount of erosive wind and water action influencing rates at which parent materials are weathered or removed. Climate also determines the kind and quantity of vegetation found in various landscapes and the amount of organic material added each year; the water and temperature regimes regulate biological and chemical reaction rates including solution, hydration, and leaching. Human factors include tillage practices, crop rotations, fertilizer applications, water management, and other controllable practices.

The type and quantity of biota determine the kind and amount of organic materials that are returned to the soil. Biota type also influences the spatial distribution of organic material in soil. For example, grasses differ from trees in that they translocate much of the organic matter they synthesize into the soil or the root system, whereas the primary contribution from trees is through leaf drop on the soil surface. In natural grasslands, over 2.5 Mg ha^{-1} dry matter can be added to the soil each year as roots, and total root systems may contain more than 12 Mg ha^{-1} of dry matter, compared to production of only 2 to 5 Mg ha^{-1} of aboveground material (Russell, 1973). Vegetation influences many other biological processes that affect soil quality by providing energy sources for microbial processes, including N mineralization, fixation, and immobilization. Plant residues provide carbon sources for decomposition processes that ultimately sustain soil organic matter content and influence processes such as aggregate formation and stabilization.

Topography influences soil water movement, temperature, and erosion. Soils on sloping land, especially those having medium or fine texture, are highly likely to lose water as runoff. Soils in depressions usually have higher water content than soil on slopes. Sloping topographies also are subject to more water erosion than more level areas with similar land cover. Slope orientation and elevation are topographical factors that in-

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fluence local microclimate and thus influence the soil forming processes. Formation time, along with intensity (temperature, rainfall, etc.), determines the degree of soil development, a critical influence on soil quality.

Human and natural factors interact, creating many unique combinations that give rise to different soils (Arnold, 1983), each with an inherent quality that may be enhanced by increased soil biological activity. Our objectives are to illustrate these interactions, to identify indicators that might be used to evaluate human-induced effects on soil quality, and to suggest soil and crop management strategies that will sustain or improve soil quality. We also discuss past and current research findings, and offer examples of alternative management practices that may be beneficial for developing or sustaining optimum soil quality.

Soil Quality Indicators

Defining soil quality is complicated by the need to define the value of soil as related to long-term productivity and environmental quality. Consequently, selecting a suite of indicators to learn whether quality is changing requires a choice of the mechanism or process to be used as a reference. We have chosen to provide examples of physical, chemical, and biological soil characteristics as criteria that may be used to evaluate soil quality quantitatively. Nutritional quality of plants grown on the soil is also discussed as a criterion for evaluating soil quality.

Physical indicators

One physical indicator of soil quality is *soil tilth*, which Karlen et al. (1990) defined as the physical condition of a soil described by bulk density, porosity, structure, roughness, and aggregate characteristics, as related to several phenomena: transport of water, nutrients, heat and air; the stimulation of microbial and microfauna populations and processes; and the impedance to seedling emergence and root penetration. We suggest that tilth could be used to measure soil quality because many soil, water, and crop management practices influence the physical, chemical, and biological attributes that reflect overall soil quality. Karlen et al. (1990) proposed the term *tilth-forming processes* for the combined action of physical, chemical, and biological processes that bond primary soil particles into simple and complex aggregates and aggregate associations, thereby creating specific structural or tilth conditions. Since current research at the USDA-ARS National Soil Tilth Laboratory is directed toward quantifying mechanisms and processes that are important contributors to soil tilth (Karlen and Erbach, 1990), many of those results may also be useful for assessing soil quality in the U.S. and around the world.

Resistance to wind and water erosion is another physical indicator of soil quality. This characteristic is important because in the U.S. alone, agricultural activities contribute nearly three billion tons of sediment and over 9.5 million tons of nutrients to surface waters each year (Baily and Wadell, 1979). This sediment, and the nutrients and pollutants that it contains, are the most significant agricultural non-point-source pollutants of surface waters. Disregarding significant impacts on biological systems or losses of dissolved pollutants such as nitrates and pesticides, the Conservation Foundation (Hansen et al., 1988) estimated that in 1984, sediment and associated pollutants imposed a yearly cost of $13 billion in the United States alone.

Soil quality as measured by productivity also is affected by erosion. Lal (1988) reported that because of soil degradation, grain yields in some African countries are lower today than they were a generation ago. Whitlow (1987) reported that erosion rates of up to 40 Mg ha^{-1} yr^{-1} in Zimbabwe and several other parts of Africa often make it difficult to increase maize (*Zea mays* L.) yields, thus threatening the long-term viability of farming and development of communal lands. Soil loss in Zimbabwe is not uniform: erosion is negligible in 60% of the country. However, the most serious erosion affects 10% of the land in the granitic dome terrain, which also is the most densely populated area of communal lands (Whitlow, 1987).

Chemical indicators

Chemical indicators that may be useful for evaluating soil quality include inherent soil fertility properties, such as pH, cation and anion exchange capacities (CEC and AEC), total and available plant nutrients, and salinity; and nutrient cycling or transformation rates. Studies such as those by Kubota (1980), which have identified relationships between trace element deficiency and toxicity in plants and in animals that eat plants grown on those soils, provide one example of how soil chemical properties might be used to assess soil quality. Another example is studies of nutrient interactions, for example the interactions among K, Ca, and Mg that influence soil-plant-animal nutrient disorders such as grass tetany or hypomagnesemia (Grunes et al., 1970; Wilkinson et al., 1987).

The efficiency of nutrient cycling may provide another indication of soil quality. By studying chemical transformations such as mineralization, immobilization, and leaching, that can occur at microsites formed by soil aggregates, it may be possible to understand some basic mechanisms that cause the quality of soils to differ. For example, Beauchamp and Seech (1988) reported that although NO_3-N concentrations were not significantly different for the aggregate sizes they evaluated, their data suggested that denitrification potential is much greater in small (<0.5 mm) aggregates than in larger ones. Assuming soil aggregation to be a physical indicator of soil quality, their work suggests that soil quality may affect water quality by influencing the transport and fate of compounds of both human and natural origin.

Biological indicators

Microbial activity and natural processes of respiration, mineralization, and denitrification might be useful biological indicators of soil quality. Examples of these relationships have been presented by Doran et al. (1990) and Linn and Doran (1984a,b). They demonstrated that for a wide range of soils, aerobic microbial activity increased linearly with water content between 30 and 60% water filled pore space (WFPS). Between 60 and 70% WFPS, aerobic microbial activity declined, presumably because the additional water presented a barrier for diffusion of oxygen to and waste products away from soil microorganisms. Given an adequate supply of available carbon and

NO_3-N, there was very little denitrification at 60% WFPS (Doran et al., 1990; Linn and Doran, 1984a,b), but it increased exponentially at WFPS exceeding 70 to 75%.

Biological activity also influences soil quality through its effect on physical properties such as soil aggregation. For example, Molope (1987) suggested that the stability of soil aggregates is due to the combined mechanical and biological action of microorganisms and their products of decomposition. Tisdall and Oades (1982) suggested that roots and fungal hyphae are the major binding agents in soil aggregates larger than 200 μm, with hyphae and bacteria important in aggregates larger than 20 μm. Fungal hyphae appear to be temporary binding agents that can hold soil particles together for up to several months (Jastrow and Miller, 1991). However, as soil aggregates break apart upon wetting, soil pores become blocked and the potential for runoff and soil erosion during rainfall events is increased (Tisdall and Oades, 1982). Therefore, if oxygen, water, and essential nutrients such as N and P are available in adequate amounts, any management strategy resulting in the addition of an organic carbon source will enhance microbial activity and subsequently improve soil quality by increasing aggregate stability and resistance to erosion.

New assays are needed to understand the effects of alternative soil and crop management strategies on biological factors influencing soil quality. Molope (1987) indicated that ergosterol contents were highest in soils with high organic matter and that concentrations were correlated with increases in soil aggregate stability when measured turbidimetrically. Unpublished results (N.S. Eash, 1991) also show that the ergosterol assay developed by Grant and West (1986) is a sensitive measurement of fungal biomass that correlates well with total N, total C, soil respiration, soil microbial biomass, and wet aggregate stability. These findings suggest that ergosterol may provide a biological assay for evaluating soil tilth, an indicator of soil quality.

Nutrient dynamics within an agricultural production system also can be used to assess soil quality. Studies showing the differential behavior of inorganic and organic P forms (Agboola and Oko, 1976; Harrison, 1978; Sharpley, 1985; Tiessen et al., 1983) on the dynamics of soil P cycling provide several examples. Growing cotton (*Gossypium hirsutum* L.) for 60 years (1913-1973) on a Mississippi Delta soil (Dundee silt loam) with no reported application of fertilizer P had no appreciable effect on inorganic P concentrations (Sharpley and Smith, 1983). However, there was a sharp decrease (223 to 93 mg kg^{-1}) in organic P content between the virgin and cultivated surface (0-15 cm) soil. Mineralization of organic P apparently replenished the inorganic pool and provided available P during this period. The important soil quality attribute demonstrated by this study is the P buffering capacity, which could mask effects of poor management, specifically lack of fertilizer nutrient application to replenish nutrients removed by crop production.

Nutritional indicators

Assessing the nutritional quality of plants in relation to the soil upon which they are grown also has been suggested as a method for assessing soil quality. This is a complicated process, even though inherent characteristics of the soil and those that result from use and management can affect plant composition and, at times, their nutritional quality (U.S. Plant, Soil, and Nutrition Laboratory Staff, 1965). The effects of soil on the nutritional qualities of plants cannot be explained through broad generalizations; they must be given for specific nutrients, soils, plants, animals, and diets.

Allaway (1971) stated that assays for nutritional quality are extremely difficult to implement because concepts of nutritional quality can be defined using two substantially different types of criteria. One definition focuses on concentrations of nutrients in the plants, without recognizing the changes associated with consumption of the plant by animals or humans. This was the focus for most publications listed in extensive bibliographies on the "Effect of Fertilizers on Food-Crop Quality" prepared by the Commonwealth Bureau of Soils and reviewed by Allaway (1971). The second definition of nutritional quality focuses on plant composition plus an observed effect upon the human or animal that eats the plant. This definition is more rigorous than the first, but it quickly limits the number of observations available to attempt to establish clear relationships, especially between food quality and soil quality. In developed countries, learning the effect of any one soil or plant on human health becomes even more difficult because people obtain their food from many sources. Thus the nutritional quality of an individual plant becomes dependent upon its role in multicomponent diets ((U.S. Plant, Soil, and Nutrition Laboratory Staff, 1965; Allaway, 1971, 1975).

Questions regarding the relationships between soil quality and food quality are not new. Brandt and Beeson (1951) postulated that soil fertility and crop nutrient content were related, but found evidence that such relationships were never simple and often not direct. Howard (1947) hypothesized that fertilization with organic composts resulted in a crop with better nutritional quality than if the same crop were grown with mineral fertilizers. Brandt and Beeson (1951) concluded that to test fully the validity of that hypothesis, it would be necessary to conduct animal feeding trials where the entire ration was formulated from crops grown using those two management practices. They recommended that such studies run at least through breeding, and preferably for several generations, to satisfy all conditions implied in the original hypothesis. With such criteria, they concluded that the time and cost of studies to test this hypothesis adequately with regard to human health would be "staggering." Therefore, they limited themselves to how organic and mineral fertilizers influence certain crops' content of ascorbic acid, carotene, Fe, and Cu. No significant differences could be attributed to the source of plant nutrients.

Allaway (1975) concluded that the effects on animal growth of feeds grown with organic versus inorganic fertilizers were not consistent, because the basic function of plants in the food chain is to convert inorganic compounds to organic compounds. He noted that when organic materials containing essential elements are added as part of the management practices, soil microorganisms break down the organic materials into inorganic forms. The

essential inorganic ions are then taken up by plant roots and synthesized into new organic materials within the plant.

Allaway (1975) suggested that a more important reason for adding organic materials to soils was to recycle nutrients without damaging the environment. He concluded that rather than affecting the nutrient quality of the crop, the primary benefit of these materials is improvement of soil physical properties, including water and nutrient retention capabilities, tilth, resistance to crusting by raindrop impact, and resistance to erosion by wind and water.

He also stated that some organic materials can be very useful because they provide a steady, slow release of plant nutrients. However, crops growing on soils to which organic materials low in nitrogen were recently added will suffer from N deficiency. He remarked that excessive use of organic materials near large feedlots or poultry houses has been shown to result in problems such as groundwater contamination, nitrate toxicity, and grass tetany. He also concluded that because of the amounts of crop residue returned to the soil, so-called commercial farms often are the biggest users of organic nutrient sources.

Grunes and Allaway (1985) commented that worldwide, deficiencies of calories and protein are the most crucial human nutrition problems, and that modern fertilizers have contributed to increased crop yields, thereby reducing the severity of protein-calorie malnutrition. They stressed that plant nutritional quality is controlled by the concentration and bioavailability of essential nutrients and potentially detrimental substances in the plant, with reference to the requirements and tolerances of the person or animal that consumes the plant as part of a specific diet. They also stated that no plant species, regardless of the quality of the soil it grows on, can supply all the nutrients required by any animal. Thus, without rigorous evaluation, generalizations and statements attributing either good or bad nutritional effects to soil quality are likely to be invalid and should not be made.

Management Strategies

No single soil and crop management strategy can be developed and implemented across all physiographic regions to sustain or improve soil quality, because human-induced and natural factors are not constant. Soil and crop management practices must be optimized according to inherent soil and climatic constraints and social structures.

An example of how management strategies affect soil quality is provided by studies in northern Thailand that measured soil changes associated with the cropping phase of shifting, slash-and-burn cultivation (Tulaphitak et al., 1985a,b). Burning resulted in a short-term nutrient enrichment, but severe erosion quickly resulted in a serious loss of plant nutrients, as well as increased soil bulk density, and decreases in porosity, tilth, and soil water retention.

Soil organic matter is the component that showed the greatest decline when virgin prairie was broken for cultivation (Melsted, 1954; Bauer and Black, 1981). Organic matter also declines more rapidly with cropping systems involving fallow than with continuous cropping (Unger, 1982). Fortunately, soil organic matter is a controllable factor that can be modified by soil and crop management practices.

In a review summarizing the need for more emphasis on soil organic matter, Boyle et al. (1989) suggested that returning carbon to the soil is "a necessary expense that insures a sustainable harvest." Soil carbon must be given high priority in establishing criteria for assessing soil quality because of its influence on aggregate stability (Tisdall and Oades, 1982; Chaney and Swift, 1984; Cheshire et al., 1984), which subsequently affects water infiltration, retention, runoff, and other soil quality indicators.

Nutrient cycling, physical attributes such as aggregate stability and resistance to erosion, and other indicators of soil quality all are influenced by the organic or biological component. Therefore, soil and crop management strategies that focus on soil organic matter and related biological components appear to be the best way to give the soil the resiliency or buffering capacity needed to resist changes caused by human and natural factors. We suggest that practices such as conservation tillage, cover crops, and crop rotations have the highest potential for changing soil organic matter content, and that they are most likely to improve soil quality in the U.S. and around the world.

Conservation tillage

Conservation tillage has been a focus of soil and water research for nearly four decades because it can reduce soil loss significantly (Moldenhauer and Wischmeier, 1960; Taylor et al., 1964), and improve water use efficiency by increasing infiltration and decreasing evaporation (Smika and Wicks, 1968; Unger and Phillips, 1973; Smika and Unger, 1986). Significant progress has been made in developing practices tailored to different soils, geographic regions, and crop rotations (Erbach et al., 1980; Logan et al., eds., 1987; Sojka et al., 1991), but unanswered questions impede adoption of these practices (Mannering et al., 1987; Karlen, 1990).

Reduced or conservation tillage practices that are tailored to local soil and climatic conditions may be one of the best strategies for improving soil quality through increased soil biological activity and organic matter content. This favorable attribute of conservation tillage became recognized as soils at many research sites attained new equilibria (Table 1) and there was increased emphasis on quantifying changes in soil carbon and associated physical, chemical, and biological properties (Bruce et al., 1990).

A change in management system can increase soil carbon content over time. For example, conservation tillage by definition must maintain at least 30% surface residue cover after planting to reduce soil erosion by water; where soil erosion by wind is a primary concern, the practices must maintain at the equivalent of at least 1.1 Mg ha^{-1} of flat small grain residue on the surface during critical erosion periods (Mannering et al., 1987). Tillage systems that generally meet this definition include no-till or slot planting, ridge-till, strip-till, mulch-till,

Table 1. Selected soil and crop management studies showing opportunities to increase soil carbon concentrations.

Location	Practices	Soil carbon ($g\ kg^{-1}$)	(Depth) (mm)	Reference
Piedmont	Disk/winter fallow/sorghum	6.6	(0-15)	(Bruce et al., 1990)
	Disk/winter fallow/soybean	6.8		
	Cons-till/cover crop/sorghum	18.4		
Coastal Plain	1 year conservation tillage	12	(0-25)	(Karlen et al., 1989)
	2 years conservation tillage	18		
	3 years conservation tillage	17		
	8 years conservation tillage	30		
	1 year conservation tillage	11	(25-50)	
	2 years conservation tillage	16		
	3 years conservation tillage	14		
	8 years conservation tillage	26		
Great Plains	Conventional tillage	9.9	(0-76)	(Bauer and Black, 1992)
	Stubble mulch	14.9		
(sandy texture)	Grazed	23.8		
	Relict grassland	27.9		
(medium texture)	Conventional tillage	18.2	(0-76)	
	Stubble mulch	17.6		
	Grazed	32.7		
	Relict grassland	43.1		
(fine texture)	Conventional tillage	23.7	(0-76)	
	Stubble mulch	27.7		
	Grazed	41.9		
	Relict grassland	54.0		
South Africa	8 yrs moldboard/disk-tillage[1]	10.7	(0-100)	(Agenbag and Maree, 1989)
	8 yrs tine-tillage	13.3		
	8 yrs no-tillage	14.1		
	8 yrs moldboard/disk-tillage[2]	6.8		
	8 yrs tine-tillage	15.1		
	8 yrs no-tillage	20.2		

[1]Monoculture wheat cropping system
[2]Wheat-after-pasture cropping system.

and reduced-till. By maintaining this residue on the surface, new equilibrium levels of soil carbon will be achieved. Unfortunately, as shown by the decline in soil organic matter when native vegetation was tilled, soil organic matter levels that have been increased gradually with conservation tillage can decline quickly if intensive tillage and manipulation of the soil and crop residues is resumed.

A major limitation to conservation tillage in semiarid regions is low production of residue by dryland (non-irrigated) crops. This is exacerbated when residues are removed for other purposes (Unger et al., 1990). Consequently, residues may be inadequate to protect the soil against erosion, improve water conservation, and provide abundant organic materials for intensive microbiological activity.

Cover crop contributions

Growing cover crops between cash or grain crops is a management strategy that may be useful for improving soil quality. Growing cover crops slow runoff and protect the soil from the impact of raindrops. When dead, they add organic matter to the soil and increase permeability, and thus increase infiltration, slow runoff, and decrease erosion (Pieters and McKee, 1938). Cover crops reduce leaching of N, K, and possibly other nutrients, especially on sandy textured soils. On fine-textured soils, cover crops have been shown to improve physical properties of aggregation, porosity, bulk density, and permeability (Rogers and Gid-

dens, 1957). By providing an additional carbon source and recycling nutrients, cover crops can increase microbial activity and often increase soil aggregation. This was demonstrated by Ram et al. (1960), who showed a 30% increase in soil aggregation when cover crops and woodchips were added.

Zhu et al. (1989) conducted a no-till study with soybean [*Glycine max* (L.) Merr.] on a Mexico silt loam (fine, montmorillonitic, mesic Udollic Ochraqualf) using common chickweed (*Stellaria media* L.), Canada bluegrass (*Poa compressa* L.), and downy brome (*Bromus tectorum* L.) as winter cover crops. They found that these plants increased soil cover by 30 to 50% during the critical erosion period of late spring to early summer. Compared to the check, mean annual soil losses from the chickweed, downy brome, and Canada bluegrass were decreased by 87, 95, and 96%, while runoff was reduced by 44, 53, and 45%, respectively. This shows that cover crops can improve both water quality and soil quality by accumulating and retaining nutrients, and reducing soil erosion.

Where legumes are used as cover crops, they provide additional N through biological fixation for subsequent grain crops (Smith et al., 1987). Cover crops also provide residual effects, as was demonstrated by McCracken et al. (1989), who found that growing hairy vetch (*Vicia villosa* L. Roth) as a winter cover crop for 10 years increased N uptake by a subsequent corn crop by an average of 20.4 kg ha^{-1} and resulted in higher grain yields.

In the southern U.S., cover crops such as crimson clover (*Trifolium incarnatum* L.) are being used successfully in many locations (Frye et al., 1988), but limited germplasm currently prevents wide usage in the northern Corn Belt. Winter rye (*Secale cereale* L.) and Italian ryegrass (*Lolium perenne* L.) have both been shown to be very effective cover crops for reducing leaching losses of residual N (Brinsfield et al., 1988; Staver and Brinsfield, 1990; Martinez and Guiraud, 1990). Because of their high biomass production they also can provide substantial carbon inputs into soil. A disadvantage of winter rye is its rapid growth during early spring, which can deplete available soil water supplies and stress the primary crop. This has been reported for sandy soils in the southeastern U.S. (Campbell et al., 1984) and observed in on-farm experimentation in Iowa (Karlen and Doran, 1991). Use of oats (*Avena sativa* L.) instead of rye as a cover crop is being evaluated in Iowa because it grows rapidly during autumn, but freezes during winter and does not compete for soil water reserves in spring (S.J. Corak, personal communication, 1991).

Use of cover crops to improve soil quality may require new management practices for the primary grain or cash crop. Initial results of on-farm cover crop investigations with ridge-tillage suggest that lower mineralization of organic matter and greater denitrification losses before planting reduced the availability of soil N and created apparent N deficiencies in subsequent corn crops (Doran et al., 1989; Karlen and Doran, 1991).

Crop rotations

Increasing temporal and spatial diversity by using different crop rotations may improve soil quality by mimicking natural ecosystems more closely than current agroecosystems. Narrow strip intercropping systems containing corn, soybean, and small grain/legume are being evaluated by a Leopold Center Research Issue Team in Iowa to determine the impact of this strategy on productivity and environmental quality. Several studies have focused on two crop strips, particularly corn and soybean (Francis et al., 1986). Including a third and fourth crop creates unique micrometeorological and soil conditions, and unique crop responses, especially in the border positions (Garcia et al., 1990). Both corn and oat yields tend to increase in narrow strips compared to single crop production in a larger field. Whether soybean yields are depressed depends on seasonal weather patterns (Cruse, 1990).

Alley cropping, which involves narrow strips of complementary crops, including woody or herbaceous perennials, is a management strategy that may be useful for improving soil quality. Species such as *Cassia siamea*, *Gliricidia sepium*, and *Leucaena leucocephala* can provide nutrients to corn and other grain crops and protect the soil from erosion by increasing residue cover. Chen et al. (1989) reported that growing *Leucaena* for 14 months at the International Institute for Tropical Agriculture (IITA) in Nigeria increased soil pH, K, organic carbon, and corn yield, while decreasing soil erosion. Kang et al. (1985), also working at IITA, reported that *Leucaena* stands established 8 years earlier remained viable and produced approximately 200 kg N ha^{-1} yr^{-1} from 1981 to 1983.

Alley crops can be used as a mulch or incorporated as green manure, which results in better N use efficiency (Wilson et al., 1986). Soil water retention increased when alley crops were used as mulch, and mulching increased germination rates by decreasing soil temperature. In areas of low rainfall, alley cropping can compete with corn for soil water, but Kang et al. (1985) reported that *Leucaena* develops a deep rooting system and extracts most of its water from depths greater than 50 cm. They concluded that competition between leucaena and corn for water is small in deep soils without root restricting layers.

The effect of alley cropping on corn productivity and soil quality depends on the alley crop species. Yamoah et al. (1986) reported that *Cassia* maintained a high soil microbial biomass carbon, presumably because of its slow rate of decomposition. Soil bulk density was lower under all alley crop species evaluated. Soil N increased with *Cassia* and *Flemingia*, but decreased with *Gliridia*. *Cassia* and *Gliridia* were promising species for Nigeria. Hulugalle and Kang (1990) also concluded that alley crops that produce large quantities of prunings that decompose slowly will improve the soil.

Soil and Crop Management Research Challenges

A critical research challenge for developing a strong soil and crop management basis for improving soil quality in the U.S. and around the world is to develop an increased understanding of soil microbial population dynamics in response to various soil and crop management strategies (Eash et al., 1990). Management strategies that add or maintain soil carbon

appear to have good potential for improving the quality of our soil resources.

Efforts should be placed on the development of assays such as those for ergosterol, which are anticipated to be useful criteria for improving our understanding of soil tilth and soil quality, and for assessing long-term impacts of alternative soil and crop management systems. The potential for improving soil quality by using organic materials such as lawn clippings, newspaper and cardboard, or food-processing wastes such as whey (Watson et al., 1977) or molasses fermentation solubles (Henning and Krogmeier, 1990) also warrants further investigation. Criteria for using non-traditional carbon sources to increase soil organic matter need to be developed, because it also may alleviate a solid waste disposal problem. Germplasm allowing widespread use of cover crops needs to be identified and made available. Concerns slowing adoption of conservation tillage practices should be addressed. With soil and crop management strategies such as these, we will better understand the physical, chemical, and biological interactions caused by human and natural forces, and soil quality may be improved.

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Cover Crops May Reduce Vineyard Chemicals

In a LISA project involving university researchers, extension agents, and grape growers, the use of legume cover crops is being studied as a way to eliminate or substantially reduce the need for many pesticides, herbicides, and nitrogen fertilizers in California vineyards. Researchers' goals are to examine the potential for these low-input techniques to manage several key vineyard arthropod pests, to use cover crops and other cultural techniques to manage weeds in vine rows, and to confirm the potential of legume cover crops as alternatives to synthetic fertilizers.

The research is being conducted on commercial farms in several of the most important grape-growing regions of California, where the three primary uses for the grapes are raisins, table grapes, and wine. Participants hope to determine the direct costs and benefits to producers of low-input techniques, and to develop guidelines for the use of those techniques for pest, weed and vine-nutrition management. For more information, contact: Frank G. Zalom, Project Coordinator, University of California, Davis; (916) 752-8350.

Soil crusting in relation to global soil degradation

Malcolm E. Sumner and William P. Miller

Abstract. *The formation of crusts or seals at the soil surface is exceedingly important in determining how much rainfall infiltrates into the soil and how much runs off, causing soil erosion. This paper explores the processes involved in the formation of crusts, such as raindrop impact and clay dispersion, to formulate a picture of the mechanisms involved. We discuss the major consequences of crusting, namely, runoff, erosion, and impaired seedling emergence, and present strategies to reduce soil degradation. Examples are offered from many parts of the world.*

Key words: dispersible clay, infiltration, runoff, erosion

Introduction

It has been known for many years that soils throughout the world form crusts, but the effects of soil crusting on runoff and erosion have not been as widely acknowledged. This is particularly true of the sandy and sandy loam soils that occur in well-watered areas of the world, in contrast to soils occurring in arid and semi-arid areas, which have been shown to crust as a result of sodic conditions, that is, elevated levels of sodium (Na) and low electrolyte concentrations (Kemper and Miller, 1974; Shainberg et al., 1989). In non-sodic soils, crust formation has been associated with low organic matter and high silt contents, and with low aggregate stability (Kemper and Miller, 1974).

In many parts of the world, some soils are highly erodible, while others in the same region are much less so; no satisfactory explanation has been advanced, although cementing agents have been thought to be important in crust formation (Uehara and Jones, 1974). This is true in the southeastern U.S. (Miller and Radcliffe, 1992), South America (Roth, 1992), Africa (van der Watt and Valentin, 1992), Australia (Chartres and Oades, 1992), the midwestern U.S. (Gupta et al., 1992) and the Middle East (Shainberg, 1992); hard-setting surface layers and high rates of runoff have been noted in each of these regions. Although some processes involved in crusting and its consequences have been studied and documented (Luk et al., 1990; Norton, 1987), clay dispersion has not been prominent among them.

Because crust formation results in reduced pore space at the soil surface, it decreases infiltration, thus causing runoff and erosion. In many of the above regions, cultivation in the last 200 years has resulted in severe soil degradation stemming from nutrient depletion, salinity, sodicity, runoff and erosion. Often this has resulted in land being abandoned. These processes of degradation continue today. As a result, deep fertile soils have been transformed into exposed subsoils, and clear rivers and lakes have become clogged by heavy stream sediment loads. There is little doubt that soil crusting has been one cause of these agricultural and environmental disasters (Sumner and Stewart, eds., 1992).

Crusting, in the following discussion, means the process of aggregate breakdown followed by clay dispersion that occurs at the soil surface under the impact of rainfall, forming a thin seal that is less permeable than the underlying soil. Upon drying, the strength of the crust increases, presenting a barrier to seed emergence. The discussion that follows will demonstrate the principles involved in the formation of crusts, and show in detail the consequences of this process for agricultural production. Crust formation is ubiquitous, occurring in similar ways on widely different soils.

Clay Dispersion

To be able to form a clear picture of the mechanism of crust formation, it is necessary to be familiar with clay dispersion and its consequences. Crusting soils typically contain dispersible clay, which with mechanical energy (raindrop impact), breaks free of its attachment within aggregates and goes into suspension. Stable clay suspensions, which remain cloudy for extended periods, are obtained in the laboratory for the purposes of conducting a particle size analysis of a soil by mechanically agitating the soil in the presence of a dispersing agent such as a mixture of sodium polyphosphate and sodium carbonate. The dispersing agent causes high exchangeable Na and low electrolyte concentration, which make the clay particles repel each other after being separated by mechanical energy (Sumner, 1992). For many years, it was thought that only clay in soils with high levels of exchangeable Na (i.e., with more than about 5 to 10% of the exchange capacity occupied by Na) was dispersible. This has proved not to be true; many soil clays are dispersible at the low electrolyte concentrations likely in soils of humid regions, even though the levels of Na are low or zero (Miller and Baharuddin, 1986; Shainberg et al., 1989). Dispersible clay is measured by gently shaking soil in deionized water (Miller and Baharuddin, 1986). Dispersible clay is typically greater than 50% in Georgia topsoils (Figure 1), and reaches 80% in some topsoils from other regions.

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There is evidence that elevated levels of potassium (K) and magnesium (Mg) also can contribute to clay dispersion (Levy et al., 1988; Keren, 1989; Levy and van der Watt, 1990; Shainberg, 1992). However, low electrolyte concentration in the soil solution (usually below 5 $mmol_c\ l^{-1}$) is the key to clay dispersion under soil conditions in humid zones. This is illustrated in Figure 2, where the clay from a Cecil soil remains in suspension below a concentration of about 5 $mmol_c$ $CaSO_4$ l^{-1} (added as gypsum). Above this concentration, most clay systems will flocculate, that is, form attractive bonds between clay platelets, giving rise to compound particles (flocs) that settle out. Various ligands such as phosphate, silicate and low molecular weight organic acids promote clay dispersion by reversing positive charges on clay surfaces, thus increasing the repulsive potential between clay particles (Sumner, 1992). This is illustrated for oxalate and citrate in Figure 3. Thus, clay dispersion and the attendant enhancement of soil crusting largely are chemical processes, catalyzed by the mechanical energy of raindrop impact.

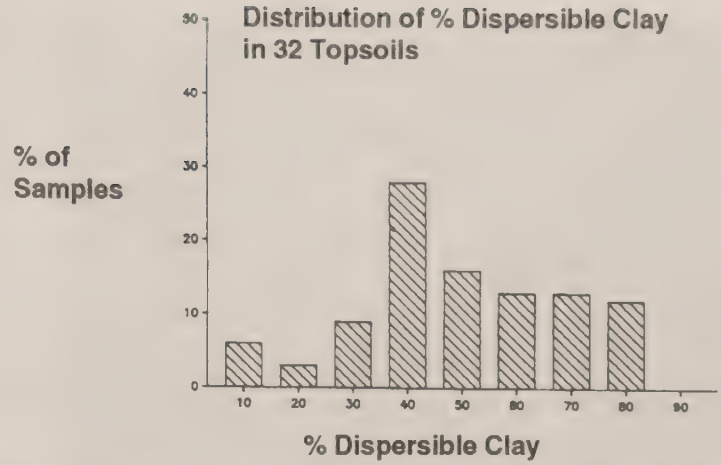

Figure 1. Frequency distribution of dispersible clay in 32 Georgia topsoils (Miller and Radcliffe, 1992).

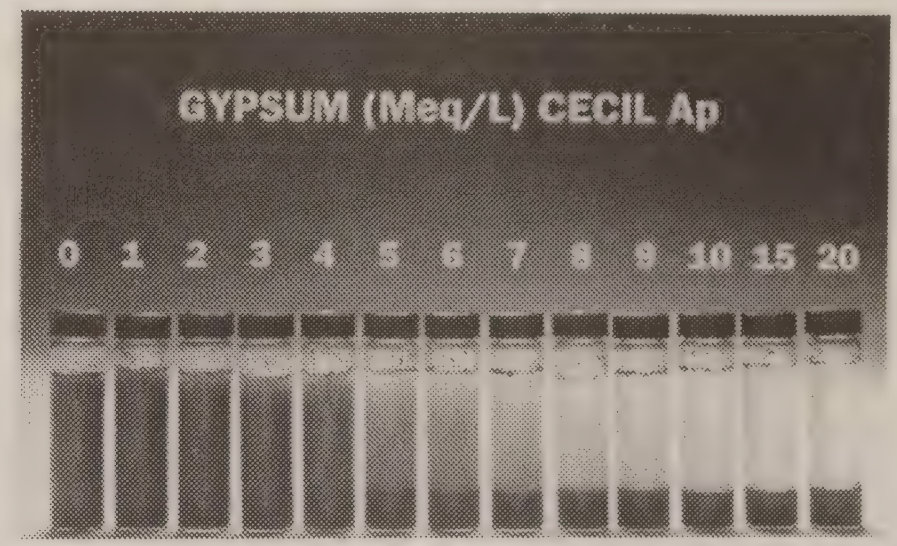

Figure 2. Effect of gypsum concentration on flocculation of clay from a Cecil topsoil.

Crust Formation

Impacting raindrops supply the energy to disrupt soil aggregates, allowing many of the clay particles to separate from sand and silt particles, disperse, and then move into and clog the water-conducting pores at the soil surface (Luk et al., 1990; Shainberg et al., 1989). This results in what has been termed a "washed-in" layer, a zone in which the pore space has become clogged to form a thin seal underlying a "washed-out" layer, consisting of clean sand grains on the surface (Shainberg et al., 1989). These symptoms, illustrated in Figure 4, are diagnostic for dispersion-related crusting, provided sufficient sand is present. Below the thin seal, there often is a layer of what appears to be large pores; in fact, these are the remains of air bubbles trapped below the crust as illustrated in Figure 5.

The primary manifestation of crusting in the field is slowed infiltration rates because of the high density and low porosity of the impermeable layer formed. McIntyre (1958) was one of the first to document the low hydraulic conductivity of soil surfaces exposed to rainfall, and to associate it with washed-in layers in crusting

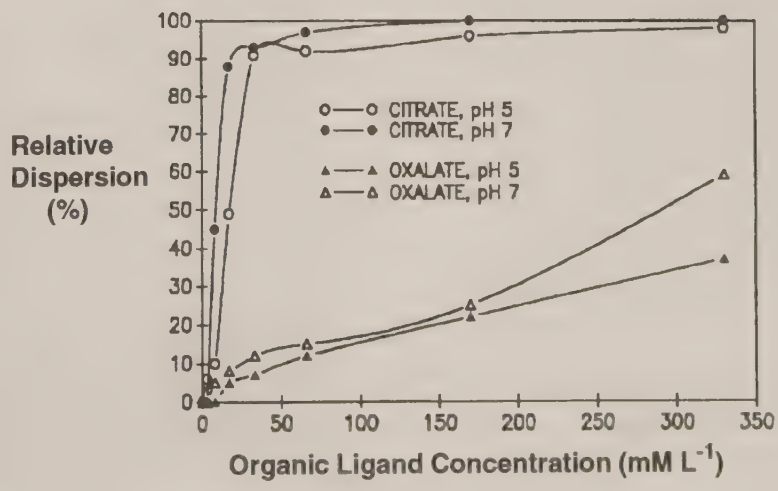

Figure 3. Effect of inorganic and organic ligands on clay dispersion.

Figure 4. Illustration of "washed-out" layer consisting of clean sand grains overlying the skin seal composed of clay particles "washed-in" to the underlying pore space on an Appling sandy loam in Georgia.

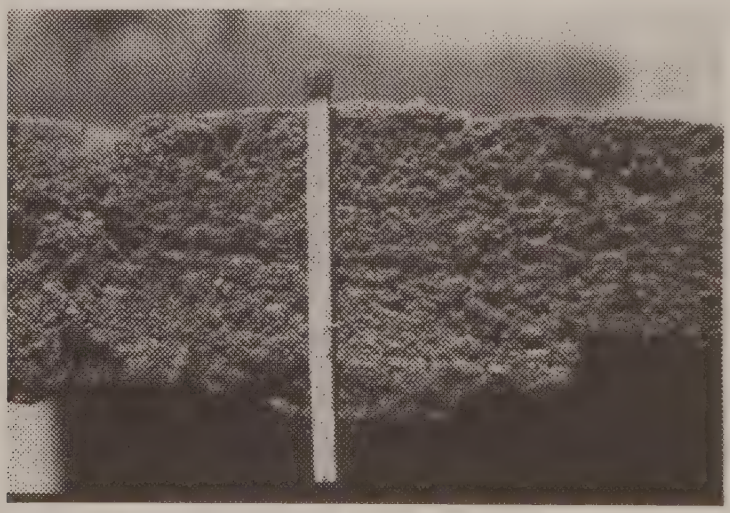

Figure 5. Transverse section of a crust on a Shorrocks soil from South Africa showing the skin seal ("washed-in" layer) and zone of trapped air bubbles below the seal.

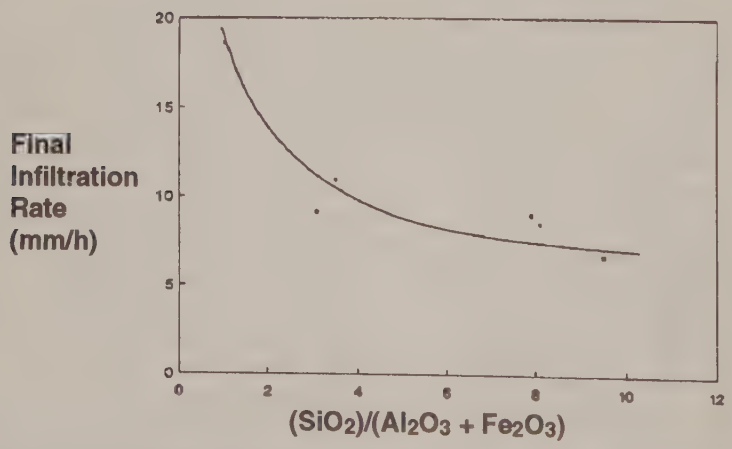

Figure 6. Relationship between final infiltration rate and silica:sesquioxide ratio (van der Watt and Valentin, 1992).

soils. Miller and Radcliffe (1992) found a highly significant negative correlation between water dispersible clay and crust hydraulic conductivity for a range of Georgia soils. A similar relationship between a measure of clay dispersibility and infiltration rate under simulated rainfall was documented earlier by Miller and Baharuddin (1986).

The resistance of certain soils to crusting has been associated with higher concentrations of organic matter and sesquioxide (Fe_2O_3 and Al_2O_3) (van der Watt and Valentin, 1992). The effects of organic matter on enhancing aggregation and inhibiting dispersion and crusting have been studied extensively; a review by Tisdall and Oades (1982) has pointed out the importance of scale in the binding of micro-aggregates by humic materials, and the stabilization of micron-sized aggregates by live and remnant root hairs and fungal hyphae.

In West and Central Africa, the positive effect of soil humus on structural stability was greater on sandy than finer textured soils (van der Watt and Valentin, 1992). Crusting hazard was greatest when the ratio of organic matter to silt + clay was less than 0.05. The beneficial effects of sesquioxides on aggregation have been demonstrated by van der Watt and Valentin (1992) for a range of soils in Southern Africa. They showed that with increasing degree of weathering, the $SiO_2/(Fe_2O_3 + Al_2O_3)$ ratio increased and the final infiltration rate decreased over a range of soils (Figure 6).

Consequences of Crusting

Soil crusts greatly reduce water transmission properties, as illustrated in Table 1, which compares the infiltration rates of a crusted and non-crusted treatment on a Rhodic Haplorthox from Brazil. In the non-crusted treatment, a straw mulch was placed on the soil surface to prevent the formation of a crust. The mulch reduces the energy of the raindrops almost to zero, which maintains the original structure at the soil surface. The results clearly illustrate the drastic reduction in the infiltration rate and the increase in runoff that occur when a crust forms.

Table 1. Effect of a straw mulch on the infiltration rate, runoff and soil loss from a Rhodic Haplorthox from Brazil under a rainfall intensity of 60 mm h^{-1} for 80 minutes (Roth et al., 1988).

Mulch treatment ($t\ ha^{-1}$)	Soil cover (%)	Infiltration rate ($mm\ h^{-1}$)	Runoff (mm)	Soil loss ($g\ m^{-2}$)
0	1	18.5	56	71
6	96	56.1	23	0

Table 2. Relationships among dispersible clay, modulus of rupture, penetration resistance and seedling emergence of soybeans on three Cecil soils exposed to simulated rainfall of 90 mm h^{-1} for 30 min (Miller et al., 1988).

Soil property	Cecil 1	Cecil 2	Cecil 3
Dispersible clay (%)	28 c[1]	52 a	36 b
Modulus of rupture (mbar)	120 b	260 a	294 a
Penetration resistance ($kg\ cm^{-1}$)	27 c	263 a	116 b
Seedling emergence (%)	69 a	28 c	59 b

[1]Values in a row followed by the same letter are not statistically different (p = 0.05).

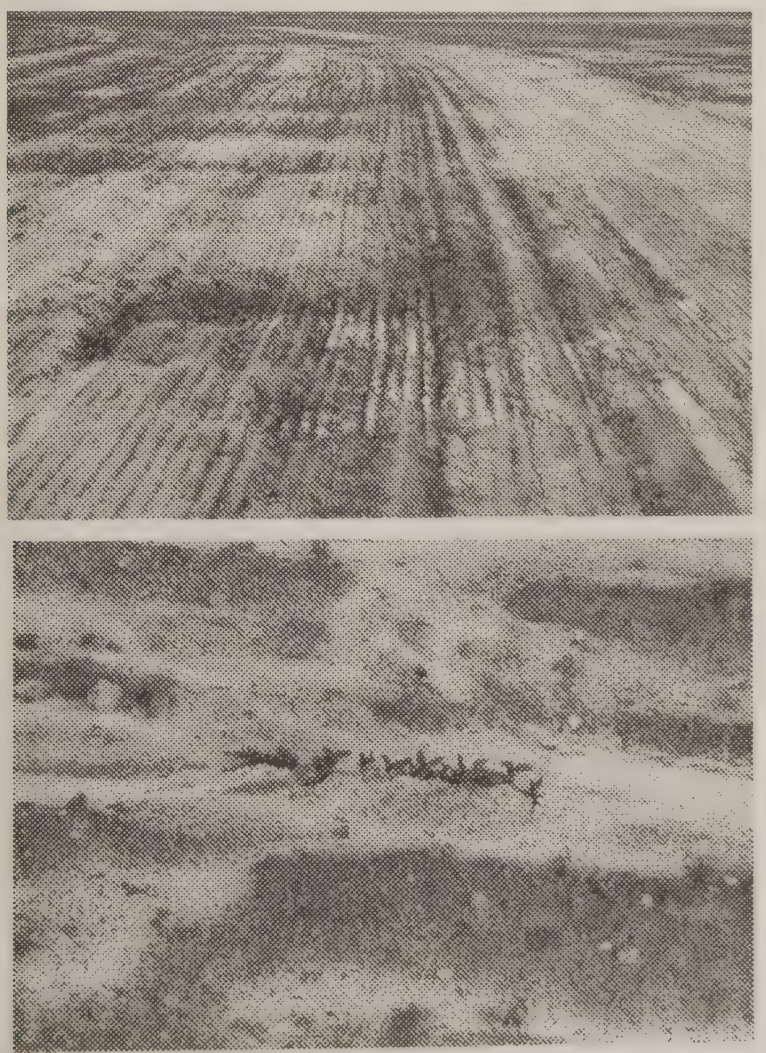

Figure 7. Poor emergence of (top) alfalfa in Saudia Arabia and (bottom) cotton in Georgia as a result of crust formation.

Runoff water from a crusted soil surface carries a heavy load of sediment; in general, crusting increases soil erosion. The strong relationship between clay dispersion and soil loss (Miller and Baharuddin, 1986) and the effect of added electrolyte in decreasing erosion by its effect on dispersion (Shainberg et al., 1989), support this contention. In the field, the high volume of runoff is likely to increase erosion further by rilling within channel flows.

After drying, crusts harden, which impairs the ability of certain crops to emerge after germination. This is illustrated in Figure 7 for alfalfa in Saudi Arabia and cotton in Georgia. Table 2 shows how dispersible clay is related to the crust's resistance to penetration by a needle penetrometer, and its effect on seedling emergence of soybeans in Georgia. The higher the dispersible clay, the greater is the resistance to penetration, which is a measure of the force a seedling must exert to emerge through the crust, and the lower is seedling emergence. Modulus of rupture, which measures the breaking strain of a crust, was also higher on the soils in which emergence was reduced.

Control of Crusting

Crust formation can be reduced or eliminated by preventing clay at the soil surface from becoming disaggregated and dispersed. This can be achieved by dissipating the energy of the falling raindrops, or by treating the soil to prevent the aggregate disruption and clay dispersion. Covering the soil with mulches, crop residues or crop canopies reduces raindrop impact. Chemical treatments also can prevent clay dispersion from the impact of raindrops on exposed soils. Examples are gypsum or other salts to increase electrolyte concentration, and polyacrylamide to stabilize aggregates.

Reduction of raindrop impact energy

Because the energy of falling raindrops is primarily responsible for disrupting aggregates and dispersing the clay, any treatment that reduces this impact will reduce the formation of crusts. The most feasible options for achieving this protection of the

Table 3. Effect of conventional and conservation tillage on water stable aggregates and final infiltration rates over three sites (slight, moderate and severely eroded) on Cecil and associated soils in Georgia (Bruce et al., 1990).

Tillage	Water Stable Aggregates[1] (%)	Final Infiltration Rate (mm h^{-1})	
		With residue	Without residue
Conventional tillage—soybean	61.7 b[2]	32.0 A[3]	23.8 C
Conventional tillage—grain sorghum	57.9 c	35.7 A	22.3 C
No-tillage—grain sorghum and crimson clover	88.6 a	49.7 B	46.3 D

[1]Measured on samples from top 15 mm of soil

[2]Values followed by the same lower case letter are not statistically different (p = 0.05)

[3]Values followed by the same upper case letter are not statistically different (p = 0.05).

Table 4. Effect of tillage on soil cover and total infiltration for six stages of growth of soybeans in Brazil (Roth, 1992).

Growth stage of soybean	Disc plow		Chisel plow		No-tillage	
	Soil cover (%)	Infiltration[1] (%)	Soil cover (%)	Infiltration (%)	Soil cover (%)	Infiltration (%)
Fallow before tillage	60	92.9	80	93.3	90	98.3
Germination	4	60.5	5	64.3	43	64.3
Flowering	70	48.9	87	51.9	98	84.6
Seed formation	50	60.6	68	79.0	95	96.7
Maturing	48	43.5	63	63.7	95	80.9
Fallow after harvest	80	70.1	95	94.5	96	94.0
Mean	52	62.8	66	74.4	82	86.5

[1]Total infiltration in % of a simulated rainfall of 60 mm h^{-1} for 1 hour

$LSD_{0.05}$ for infiltration values = 7.3%.

Table 5. Effect of phosphogypsum on the final infiltration rates for various soils.

Soil and Source	Infiltration rate (mm h^{-1})	
	Control	Gypsum
Appling—Georgia (Miller et al., 1991)	1.1	12.0
Davidson—Georgia (Miller et al., 1991)	3.2	10.9
Hamra—Israel (Kazman et al., 1983)	8	13
Greenville—Georgia (Miller and Scifres, 1988)	11	23
Unknown—California (Singer and Warrington, 1992)	2.6	4.2
Cecil—Georgia (Miller, 1987)	7.3	22.2
Wedowee—Georgia (Miller, 1987)	2.3	11.0
Rhodic Haplorthox—Brazil (Roth et al., 1986)	19.4	25.6
Shorrocks—South Africa (van der Watt and Classens, 1990)	10.1	30.0
Worsham—Georgia (Miller, 1987)	0.8	2.2

soil surface are the use of mulches and residue-based conservation tillage systems (Miller and Gifford, 1974). This is illustrated in Table 3. Under the no-tillage regime, water-stable aggregates have increased, improving the soil's ability to resist disruption. This has resulted in much higher infiltration rates than in the conventional tillage treatments. Under conventional tillage, residues on the surface markedly improved infiltration, but they had a much smaller effect in the no-tillage treatment where there already was substantial protection for the soil surface. For a Rhodic Haplorthox in Brazil, the resistance of aggregates to disruption by falling raindrops increased with increasing soil organic matter content (Roth et al., in press).

The importance of soil cover and tillage systems in promoting infiltration is illustrated in Table 4. In all tillage systems, soil cover plays a very important role in determining the total infiltration, although this effect is less pronounced in the no-till system. Because disc and chisel plowing resulted in less soil cover, infiltration was reduced on these treatments. The importance of soil cover in promoting infiltration was further emphasized by Gupta et al. (1992), who showed that for 32 silt loam to clay soils in the North Central Region of the U.S., a grass cover increased infiltration by 47% over a tilled surface.

Chemical control of dispersion

Because many soils contain clay that disperses at low electrolyte concentrations, formation of crusts will be prevented or delayed by any strategy that keeps the electrolyte concentration in the solution surrounding the clay particles high enough to promote rapid flocculation after an impacting raindrop has disrupted an aggregate. Gypsum is an ideal material for this purpose, as it dissolves rapidly up to about 30 $mmol_c\ l^{-1}$, which is adequate to flocculate most soil clays, but low enough to remain effective over a growing season in the field. By-product materials such as phosphogypsum (derived from phosphate fertilizer manufacture) and flue-gas desulfurization gypsum (from SO_2 removal at coal-fired power plants) are pure, fine crystalline materials that are available at low cost in many areas of the country. They are

effective in preventing clay dispersion, enhancing infiltration, and reducing erosion when applied at rates of 3-5 mt ha^{-1} on the soil surface (Shainberg et al., 1989). Visually, the segregation of clay from the sand particles so commonly observed on crusting soils (Figure 8, top) is prevented with gypsum applications, as illustrated in Figure 8 (bottom). The dramatic effect of surface-applied phosphogypsum in maintaining a high infiltration rate is demonstrated in Table 5 for several soils from around the world. This effect is only temporary, because the gypsum will dissolve and penetrate deeper into the soil. In addition, tillage and mixing of the surface-applied material into the plow layer will largely negate the effect.

Enhancing aggregation

The role of increased soil organic matter levels in maintaining aggregation has been mentioned as a factor in crust reduction. Soils planted to pastures (with fine, dense root distributions) or to no-tillage row crops (with high carbon inputs and limited decomposition) typically show enhanced aggregation and less susceptibility to crusting (Tisdall and Oades, 1982; Bruce et al., 1990).

The ability of humic materials to bind primary soil particles into water-stable aggregates extends to synthetic organic polymers. Materials such as polyvinyl alcohol were evaluated in the 1950s for erosion control, but were too costly despite their effectiveness in stabilizing aggregates (Raney, 1953; Ruehrwein and Ward, 1952). Polyacrylamides (PAM) of very high molecular weight (1 to 10 million AMU) have recently been evaluated at low application rates (20 kg ha^{-1}). They significantly increased infiltration rates when sprayed on the surface of crusting soils in Israel (Shainberg et al., 1990). The effectiveness of such treatments is probably limited to a few rainfall events. However, synthetic polymers may be important for controlling crust formation on cultivated land during critical periods (such as planting), or as temporary treatment for construction areas and other disturbed lands.

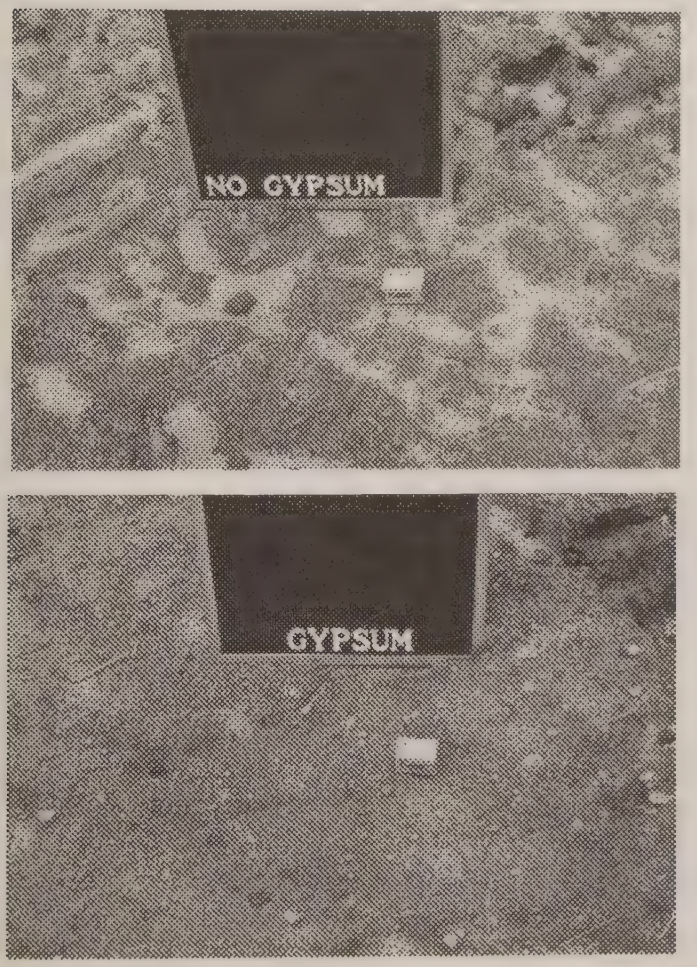

Figure 8. Comparison of surface applied phosphogypsum (bottom) and control treatments (top) in the formation of "washed-out" and "washed-in" layers leading to crust formation on an Appling sandy loam in Georgia (Miller et al., 1991). Note the segregation of sand grains in the control, which are not present in the gypsum treatment.

Summary and Conclusions

Soil crusting is both a manifestation and a cause of the global problem of soil degradation. Soils laid bare by clean cultivation are exposed to raindrop impact, which often leads to clay dispersion and the formation of a dense, impermeable surface crust. A large fraction of rainfall then runs off instead of infiltrating the soil. This makes less water available for crop growth, resulting in lowered yields, less carbon returned to the soil in crop residues, and further deterioration of soil structure. A high volume of runoff exacerbates soil erosion, which further damages the soil's physical properties and productivity.

Studies from many parts of the world have documented the occurrence and effects of crusting on widely varying soils, and directed some attention toward management solutions. The best measure of the propensity of a soil to form a crust appears to be its content of dispersible clay, which should be further investigated as a parameter to characterize soil quality. The dual role of physical forces (raindrop impact) and chemical processes (dispersion) in crusting suggests that control of crusting must address either or both these areas. Chemical treatments such as gypsum or PAM applications may reduce crusting for short periods on limited areas, but for most soils, physical protection from rainfall is the long-term solution. Reduced tillage methods, mulching, rotational pastures and cover crops have the greatest potential both to protect the surface physically, and to gradually increase soil humus levels, thereby improving aggregation and soil resis-

tance to crusting. Adapting these practices to farming systems around the world is thus a key to breaking the destructive cycle of soil crusting and degradation.

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The Organic Farming Research Foundation is offering funds for organic farming methods research, dissemination of research results to organic farmers and growers making the transition to organic production systems, and educating the public about organic farming issues. Projects should involve farmers in both design and execution, and take place on working farms whenever possible and appropriate. Proposals of $3,000-$5,000 are encouraged.

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Factors affecting the nutritional quality of crops

Sharon B. Hornick

Abstract. *Several factors can directly or indirectly affect the nutritional quality of crops. Among these are soil factors, such as pH, available nutrients, texture, organic matter content and soil-water relationships; weather and climatic factors, including temperature, rainfall and light intensity; the crop and cultivar; postharvest handling and storage; and fertilizer applications and cultural practices. This paper deals primarily with fertilizer and cultural management practices, and on certain environmental factors that affect the nutritional quality of field crops and of fruits and vegetables. Earlier research that has investigated the nutritional status of crops grown with either chemical fertilizers or organic fertilizers is discussed. These studies often have given contradictory results on crop yields and on crops' mineral and vitamin contents. Other factors, such as maturity at harvest, postharvest handling and storage, anti-nutritive components, and residues of chemical fertilizers and pesticides are reviewed with respect to food safety and quality, and their implications for human and animal health. Future research needs are identified so that comparable results and valid comparisons can be obtained to identify the best management practices to ensure that food is safe and nutritious for the consumer.*

Keywords: vitamins, protein, crop variety, organic fertilizer, postharvest handling

Introduction

A long-held tenet is that "healthy soils" will produce healthy and nutritious food that in turn will ensure healthy human beings and animals (Albrecht, 1975; Rodale, 1971). In the first half of this century the relationship between agricultural practices and the nutritional quality of food was widely debated. However, after World War II, public interest in agriculture's role in human nutrition declined because of the increased use of chemical fertilizers and pesticides which resulted in an abundance of cheap food and ever increasing surpluses of basic commodity crops. The increased use of food additives also greatly extended the shelf-life of processed foods which became widely available. Because of the abundance and availability of cheap food and the great diversity of food sources, the relationship between soil quality (especially soil management factors) and the nutritional quality of food was largely ignored. However, there has been considerable emphasis on postharvest handling and storage conditions which can significantly affect the nutritional quality of fruits and vegetables.

USDA's *Report and Recommendations on Organic Farming* (U.S. Dept. of Agric., 1980) concluded that, despite claims to the contrary, there was insufficient evidence to show that organically grown produce was nutritionally superior to produce grown with chemical fertilizers. The principal reason for this conclusion was the lack of scientifically sound and statistically valid data from experiments with properly controlled variables. An exception was that marketable produce might contain excessive amounts of pesticide residues and nitrates.

In the past, soil quality has been primarily equated with soil productivity. Today, however, the concept of soil quality has become much broader, encompassing environmental quality, food safety and quality, and human and animal health (Parr et al., 1992). This paper considers some environmental, cultural and management practices that can affect the nutritional quality of field crops and of fruits and vegetables, and discusses research needs and strategies that would help to ensure that food is safe and nutritious for the consumer.

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Specific Factors Affecting Nutritional Quality

The major factors affecting crop nutrient content, whether of field crops or fruits and vegetables, are soil factors, climate, the crop itself and the variety, management practices, and postharvest handling and storage.

Soil factors

In any region, soils vary greatly in their proportions of sand, silt, clay and organic matter, which in turn affects pH, water holding capacity, porosity, cation exchange capacity, and mineral composition. Crops such as alfalfa, grasses and blueberries require a specific range in soil pH for optimum growth. The relationship between soil pH and macro- and micronutrient solubility determines the availability of different soil nutrients to plants. This, in turn, affects the growth and yield of crops and their ultimate nutrient content.

Climate

Light intensity, temperature and rainfall, which interact to affect the nutrient content of plants, can vary considerably depending on the season and specific growing conditions (Somers and Beeson, 1948). Increases in light intensity can significantly increase ascorbic acid (Vitamin

C) and thiamin (Vitamin B_1) content of vegetables (Harris, 1975). Moreover, stresses from extreme temperatures, drought, and nutrient deficiencies can markedly affect nutrient uptake and growth of crops.

Crop and variety

Crops differ in their nutrient requirements. Nitrogen-fixing legumes do not require nitrogen fertilizer, while cereals and many vegetables and fruit crops do. Each crop has specific macro- and micronutrient requirements for optimum growth and yield. However, the nutrient requirement and final nutrient content for a particular crop also vary with the cultivar. For example, a carrot variety, Beta III, was recently developed that provides 270 mg kg^{-1} of beta-carotene, almost three times that of most commercial carrot varieties (Philipp Simon, USDA-ARS, Madison, Wisconsin, personal communication). This could help alleviate the problem of Vitamin A deficiency, which has seriously impaired human health in many developing countries. Although the development of exotic cultivars offers great potential for enhancing the nutritional quality of crops, the situation is further complicated by soil climatic factors and site specific considerations.

Lantz et al. (1958) reported that local growing conditions can affect the protein content of different varieties of dried beans (Table 1). Salunkhe and Desai (1988) emphasized that the ascorbic acid and carotenoid levels of different vegetables grown at six geographic locations varied significantly. Nevertheless, they concluded that "because plant foods are widely distributed from the point of growth, local growing and cultural conditions do not have any impact on the occurrence of specific nutrients in vegetables sold in supermarkets." This conclusion may not be valid where vegetables are grown largely in household gardens, or on farms close to local markets.

Table 1. Effects of cultivar and location on protein content of dried beans (% protein) (Lantz et al., 1958).

Variety	Locations			
	Deming (4300 ft)	Estancia (6000 ft)	State College (4000 ft)	Mean
295	20.0	30.8	22.8	24.5
641	20.9	32.1	24.8	25.9
'Michelite'	23.8	34.4	25.7	27.9
'Red Mexican'	19.9	29.0	22.5	23.9
2374	19.9	30.9	24.4	25.1
2534	20.0	29.9	26.2	25.4
'Calico'	19.8	30.1	23.9	24.4
Mean	20.4	30.9	24.3	25.2

Management practices

After World War II, U.S. agriculture began a major shift from mixed crop/livestock systems toward specialized cash grain production systems. In recent decades, livestock largely have been confined to commercial feedlots. The use of animal manures and crop rotations to maintain soil tilth and fertility, was abandoned on many farms. As a result, large inputs of chemical fertilizers and pesticides were necessary to maintain acceptable crop yields (Power and Follett, 1987). Primary emphasis was placed on the development of crop varieties with maximum yield potential. Without crop rotations, animal manures, and adequate crop residues, it is virtually impossible to protect soils in monoculture systems from extensive degradation through wind and water erosion, nutrient runoff, and organic matter depletion. Consequently, there has been a decline in the tilth, fertility and productivity of many of our agricultural soils (Hornick and Parr, 1987). Moreover, environmentalists and consumers have become increasingly concerned about ground water pollution by agricultural chemicals, and their effects on food safety and quality. Because of these concerns there is a growing interest today in shifting from high-chemical input systems and monocultures to low-chemical input systems that could reduce the need for chemical fertilizers and pesticides through alternative practices of crop rotations, integrated pest management, and conservation tillage (National Research Council, 1989).

Such changes in fertilizer and management practices are likely to affect the crop nutrient content. For example, increased applications of nitrogen fertilizer often increase the yield and protein content of barley, wheat, and rye, but may not increase protein quality (Rendig, 1984). The ratio of essential amino acids (that is, those that the body cannot synthesize) to non-essential amino acids for these crops decreased with increased nitrogen application, thereby lowering protein quality. With oats and corn, increased nitrogen fertilizer resulted in higher total protein but about the same ratio of essential to non-essential amino acids. These results indicate that changes in nitrogen inputs can affect not only the protein content of some crops but protein quality as well.

Maturity, postharvest handling and storage

Variety selection, postharvest handling, and storage have received considerable attention. An important consideration is the maturity at which each crop is harvested, since it will determine losses during postharvest handling and changes in crop quality during storage. A review by Kader (1987) showed that apples and apricots picked green contained no ascorbic acid; however, if picked either half ripe or fully ripe, the amount of ascorbic acid increased to approximately 18 and 60 mg per 100 g fresh weight, respectively. Peaches were similar to apples but, by contrast, mango contained 60 mg of ascorbic acid per 100 g fresh weight when green, decreasing to 14 mg when ripe.

During postharvest handling of crops, temperature and humidity can have major effects. Some nutrients, such as ascorbic

acid, are especially heat sensitive. For example, kale kept for 2 days at 21°C contained 60% less ascorbic acid than when kept at 0°C under humid conditions; with low humidity conditions the loss increased to 89% (Kader, 1987). Likewise, nutrient losses also can occur during storage for crops such as potatoes even at optimum temperatures and humidity (Linder, 1985; Kader, 1987; Knorr and Vogtmann, 1983). Potatoes can lose from 60 to 70% of their ascorbic acid in storage, whereas changes in the riboflavin and niacin content are minimal even after 240 days in storage (Kader, 1987).

Table 2 shows some physical factors that can lead to losses of specific vitamins (Dietz and Erdman, 1989). Some vitamins, such as ascorbic acid and folic acid, are much more sensitive to heat and can be rapidly degraded during transport, storage and processing. Because major nutrient losses can occur in postharvest handling and processing, it is important that crops either are consumed or processed immediately upon harvest, or transported and stored at optimum temperature and humidity.

Table 2. Physical factors causing vitamin loss (Dietz and Erdman, 1989).

Vitamin	Losses due to:
Tocopherol	Oxidation
Ascorbic acid	Oxidation, increased by heat and light
Vitamin A	Oxidation, increased by heat and light
Carotene	Oxidation, increased by heat and light
Vitamin D	Oxidation, increased by heat and light
Thiamin	Oxidation, increased by alkalinity
Riboflavin	Light, increased by alkalinity
Pyridoxine	Light, increased by alkalinity
Vitamin K	Light, increased by alkalinity
Folic acid	Light and heat
Biotin	Alkalinity
Pantothenic acid	Alkalinity and acidity, increased by heat
Niacin	Heat stable but leachable

Pesticides and other crop contaminants

Some crops, such as legumes, root crops, beans, cruciferous vegetables and cassava, can contain anti-nutritional factors such as protease inhibitors, lectins, goiterogens, and cyanogens. Fortunately, these components usually are destroyed by moist-heat during cooking before consumption (House and Welch, 1984; Dietz and Erdman, 1989). However, other contaminants, such as mycotoxins and nitrates, can cause severe problems (Clancy, 1986). Mycotoxins are powerful carcinogens that are produced by certain fungi (molds) in corn grain, peanut, and cottonseed, when these crops are grown under stress from high temperature and moisture deficits. Nitrates ingested in food and water by infants can cause methemoglobinemia upon conversion to nitrites in infants, and can be transformed further into carcinogenic nitrosamines.

Consumers are increasingly concerned over the use of chemicals, including pesticides and preservatives, to grow and process food crops. Some residual pesticides pose greater health risks for certain segments of our population, including the sick, the elderly and children. For example, compared with adults, children eat more food per unit body weight. Therefore, exposure to harmful substances is greater because of both greater intake and a longer lifetime exposure (Thonney and Bisogni, 1989).

Organic and conventional fertilizers

The fertilizer value of organic amendments must also be considered. For example, the average N, P and K content (%) of cattle manure (1.9, 0.6, 1.4), swine manure (2.8, 1.3, 1.2) and poultry manure (3.8, 1.9, 1.8) can vary considerably (Parr and Colacicco, 1987). Similarly the average N, P, and K content for such materials as alfalfa hay (2.5, 0.5, 2.1), grain straw (0.6, 0.2, 1.1), soybean meal (7.0, 1.2, 1.5) and bone meal (4.0, 23.0, 0.0) varies with cultural, management and processing factors (Maga, 1983). Recycling these materials to soil as biofertilizers and soil conditioners can lead to considerable differences in crop response.

Knorr and Vogtmann (1983) showed that the crop variety, type of compost, and fertilizer level affected the yield of spinach, although there was no predictable pattern between the source of fertilizer and crop variety. A summary of the effect of organic fertilizers on crop yields compared with chemical fertilizers is reported in Table 3. Because of wide differences in crop varieties, soils, and agroclimatic conditions, one must exercise caution in concluding that one source of fertilizer is superior to another regarding yield. Table 4 gives a good example of how studies of organic vs. conventional fertilizers can be confounded by unequal fertilizer levels, not only between years but within treatments and between treatments. Obviously, it is impossible to make valid comparisons between organic and conventional sources of N, P, and K in such treatments.

Other problems in studies comparing organic and conventional fertilizers include insufficient duration, lack of replication, varietal differences, and different bases for yield and nutrient composition analyses (dry vs. wet weight) and inadequate design. Because of the many parameters that must be controlled in comparative studies, it is not surprising that confounded yield results have been reported. Consequently, contents of minerals, vitamins and other nutrients often are also confounded.

In controlled hydroponic experiments with available nitrogen as the only variable, ascorbic acid (Vitamin C) in kale decreased by more than 50% when the nitrogen rate increased from 5 mg l^{-1} to 150 mg l^{-1} (Hornick and Parr, 1989). Therefore, a possible explanation for some dis-

Table 3. Effect of organic fertilizers on crop yields relative to the use of chemical fertilizers.

Researcher	Crop(s)	Organic treatment effect
Hansen (1981)	potatoes, carrots,	0
	beetroots, kale	0
Haworth (1961)	potatoes, cabbage	+
Kansal et al. (1981)	spinach	-
Keipert et al. (1991)	apples, beets, carrots	-
	spinach, leeks, cabbage	-
Lairon et al. (1984)	lettuce	0
Lockeretz et al. (1984)	corn, wheat, soybeans	-
	oats, hay	0
Nilsson (1979)	carrots, leeks	0
	cabbage	-
Peavy and Greig (1972)	spinach	-
Schuphan (1972, 1974)	leafy vegetables	-
Svec et al. (1976)	lettuce, tomato, pepper,	0
	peas, onion, potato	0
U.S. Dept. of Agric. (1980)	wheat, corn	-
	oats	0
	soybeans	+

Table 4. Fertilizer nutrients (kg/1000 m^{-2}) applied to organic and conventionally amended garden plots, Newark, Delaware (Svec et al., 1976).

Fertilizer Material	N	P_2O_5	K2O
ORGANIC PLOT—1972			
Dairy cattle manure	1.83	1.10	1.83
Cottonseed meal	14.64	6.10	4.15
Blood meal	5.86	0.73	0.28
1972 Total	22.33	7.93	6.26
ORGANIC PLOT—1973			
1972 additions plus:			
Rock phosphate	0	48.82	0
Dairy cattle manure (mid-season)	0.91	0.55	0.92
1973 Total	23.25	47.30	7.18
CONVENTIONAL PLOT—1972			
5-10-10 fertilizer	12.20	24.41	24.41
CONVENTIONAL PLOT—1973			
1972 addition plus:			
5-10-10 fertilizer (mid-season)	7.31	14.64	14.64
1973 Total	19.53	39.05	39.05

crepancies on the effect of organic matter on vitamin C content may be related to available nitrogen, and rate of nitrogen mineralization, not just whether the fertilizer was organic or inorganic.

Another parameter that should be considered in comparing the effects of organic and conventional fertilizer sources on crop yield is the moisture content of the crop at harvest. Schuphan (1972) noted that the moisture content of organically grown crops was lower than in those grown conventionally. This could have been a factor in the study of Knorr and Vogtmann (1983) that reported that storage losses were lower in organically grown than in conventionally grown crops. For example, storage losses for organically grown potatoes, carrots, turnips and beets were 17.7, 18.0, 15.7 and 29.4% lower, respectively, than for conventionally grown crops. Thus, although the harvest yields were similar, the lower storage loss of the organically grown crops resulted in a higher final yield and starch content after storage.

Another factor that has received considerable study is the effect of excess nitrogen on the nutritional quality of crops. Excess N can diminish taste and flavor, lower resistance to diseases (rust and downy mildew), lower resistance to insects (mites and aphids), and reduce the biological value of plant protein (Schuphan, 1972, 1974; Knorr and Vogtmann, 1983; Linder, 1985).

Excess N in crops also can reduce carbohydrate synthesis, which can result in a lower content of glucose, a sugar that affects taste. Moreover, glucose is required for ascorbic acid synthesis, and there is evidence that the ascorbic acid content decreases in crops as available fertilizer nitrogen increases (Hornick and Parr, 1987).

Suppression of soil-borne plant pathogens and diseases by organic amendments such as animal manure or compost probably results from the introduction of beneficial microorganisms that are antagonistic and competitive against the indigenous soil microbial population (Lumsden et al., 1982). The often reported increase in resistance to insects may be due to the lower moisture content and resultant thicker cell wall, which would impede penetration by certain insects.

Table 5. Factors affecting nutritional quality.

Controllable	Difficult to Control
Preharvest	
Duration	Soil type
Crop	Climate (light, rain, temperature, humidity)
Cultivar	Organic matter (crop and animal residues)
Disease, insects	Planting date
Replication	Harvest date
Statistical design	
Sampling (plant part, etc.)	
Postharvest	
Storage conditions	
Post-harvest processing	
Taste/sensory evaluation panels	
Nutritional analyses/health aspects/bioavailabilty studies	

Research Needs

Many factors can affect the nutritional quality of crops, both before and after harvest. Table 5 lists factors that can be controlled, such as duration of the experiment, crop and crop cultivar, statistical design, storage conditions and postharvest handling. It also lists those that are difficult to control such as climate, soil type and disease and insect persistence.

In many comparative studies that use organic and inorganic fertilizers, certain controllable factors were not controlled. Thus, it is almost impossible to make valid and meaningful comparisons. These factors and their variable effects should be accounted for in any experimental design. The two most important considerations are first, to evaluate the effect of soil cultural and management practices on the nutritional quality of crops, and second, to assess the effect of these practices on the bioavailability of food nutrients after ingestion by humans and animals. Even if no significant differences are found for the first, we must not assume that there will be no differences in the second. Thus, a multi-disciplinary approach is needed to assess thoroughly the interaction of soil quality and human nutrition. This should involve soil scientists, plant breeders, and human nutritionists. Moreover, these studies should consider the entire array of growth factors important in both plant and animal nutrition, not just a few vitamins and mineral nutrients. Also, analyses should be conducted using the most current methods and analytical techniques. This would go far toward establishing the existence and significance of linkages between soil quality and the health status of humans and animals. If the nutritional quality and bioavailability of foods could be enhanced by improving soil quality, such information would find an immediate beneficial application where foods are produced and consumed locally, and in Third World countries whose diets consist mainly of non-diverse, vegetarian diets.

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LETTERS

Institutional/sociological links between sustainable agriculture and wildlife need further examination

As Ann Robinson correctly stated, wildlife managers and advocates of sustainable agriculture share "a great deal of common ground" (**AJAA** 6(4), 161-167). While the article's conclusion that "wildlife and fish habitat will be greatly enhanced if the movement toward more sustainable methods of farming becomes widespread" may be accurate in a general way, it fails to recognize the technical, institutional, and sociological complexity inherent in wildlife management. The connection between agrichemical usage and habitat degradation is an important linkage to recognize, but failure to place this issue and the others Robinson mentions in the context of a system is a failure to identify the "wildlife connection." I do not claim to have all of the answers; I simply write to express my views on a subject that is important to me.

Making changes in farming systems (e.g., decreased field size, altered hay cutting schedules) will benefit some wildlife species, but possibly at the expense of other species and possibly at a cost to the producer or the public. The trade-offs inherent in manipulating factors that affect wildlife and farm operations must be undertaken with clear goals in mind. The most important goal is what wildlife species you wish to manage for. It is extremely unlikely that in heavily farmed regions, there is sufficient area to manage in such a manner that every species will be given a leg up, so to speak.

As Robinson states, supporting resilient wildlife populations involves reduced loading of pollutants to natural systems. But the strategy must do more than that. The holism inherent in systems thinking and in sustainable agriculture is where the "wildlife connection" lies. I see five major areas on which we must focus to insure wildlife's future in agricultural landscapes.

1. Policy at both national and state levels must be made functional in terms of simultaneously supporting specific wildlife management objectives and profitable farming. Converting marginal (highly erodible) cropland to land that provides services to wildlife (Conservation Reserve Program) is a major opportunity. Another area of importance is the acreage flexibility provisions that relax disincentives to adoption of "innovative" farming practices such as crop rotation.

2. Federal and state agencies that traditionally have not worked closely together, such as state Departments of Agriculture and state Departments of Natural Resources, must continue current efforts to become more fully integrated by supporting cross-departmental training, open communication channels, and standardization of functions such as data collection and storage. Through enhanced institutional integration of this type, wildlife managers and the agricultural community can more effectively identify and capitalize on opportunities for mutual gains.
3. Lands that possess particular characteristics in terms of relative location or suitability for wildlife should be strategically targeted and managed to provide for the needs of specific wildlife species. In many situations the most economical way to pursue this important step is to develop farming systems (i.e., Best Management Practices) that are acceptable to producers and that provide minimum threshold habitat requirements. This approach

would keep land on the local tax roles, reinforce land stewardship as the purview of the American farmer, and avoid heavy public expenditures. In certain situations, however, acquisition or consultative land management via easements or lease agreements probably will be necessary. In such cases, the public must understand what they are buying and why.

4. Woodlot management and private forestry should be aggressively promoted and coordinated, at the landscape scale, to provide benefits to specific wildlife species. Current programs such as Forest Stewardship, the Tree Farm program, and differential property tax treatment of forested tracts could be greatly enhanced by efforts to help forest land owners obtain higher stumpage prices. Investment in forest management will follow if landowners are in a position to capture the value of their trees. However, forest cover is not universally compatible with all wildlife management goals and may not be appropriate under all circumstances.

5. Educational programming based on research must be made available to both urban and rural citizenry regarding the "wildlife connection." Practices that favor targeted wildlife species should be incorporated into State Cooperative Extension recommendations. Efforts to include wildlife management courses in the curricula of all students of natural resource disciplines should be continued.

The five items listed above represent the tools that are required to provide a place for wildlife in agricultural landscapes, but what about the process? To plan for wildlife in an agricultural landscape, I see the following steps as important:

We first need to know what we hope to accomplish. What species do we want to support?

Then we need to know how to attain this goal. What components of the environment should we manipulate? How much habitat, of what quality, will be needed? What types of Best Management Practices are likely to be compatible with the equipment, labor supply, managerial skill, goals, and values of land owners, while providing the essentials for animals to survive and reproduce?

We then will need a way of conceptualizing and predicting how manipulations we undertake will affect the environment and farm operations.

Finally, we should be prepared to monitor our progress and make changes to the program if indicated.

To portray wildlife as the beneficiary of reduced agrichemical usage and other changes in cropping systems represents a failure to capitalize on what I consider the strength of sustainable agriculture--cognizance of the interrelationships among technology, institutions, people, and the environment, and the ability to solve problems from such a position.

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Response:

Steven Wolf seems to be suggesting further examination of the institutional/sociological links between sustainable agriculture and wildlife. I do not view this as a refutation of my original discussion, but as complementary. In presentations and in other articles, I have made similar points, but in this article I chose a different focus. Nevertheless, I am wary of the underlying tone here. Some of these arguments sound much like those I have heard in the past from defenders of conventional agriculture, forestry, and wildlife approaches.

Mr. Wolf suggests the need to develop "farming systems (i.e., Best Management Practices) that are acceptable to producers and provide minimum threshold habitat requirements." The implications are that sustainable farming will not be acceptable or economically profitable, and that it will remove land from local tax roles, etc. I question such assumptions. Certainly, a growing body of research and demonstration indicates that sustainable farming (which goes beyond BMPs) is practical, profitable and offers many positive alternatives for farmers, communities, and consumers.

In addition, Mr. Wolf insists that in tracing the wildlife-farming connection, the first step "and most important goal" should be to identify which wildlife species one wishes to support. Of course, setting goals is important, since species have different habitat requirements and one must also decide the level of scale to target, whether it is the farm, the region, or the nation. However, the longtime practice of managing for one or a few species, usually "game" species, is rapidly going out of favor as being too limited. This approach has often led to a plethora of the managed-for animal, while all around, species filling other niches disappear. When this happens, landscapes become less resilient, less bountiful, and less beautiful. In place of an approach that targets species, many in the wildlife management community are moving towards methods that seek to foster biodiversity. Biodiversity depends on the restoration of functioning ecosystems that will once again support a wide variety of species that dwell in the soil, on the land, and in the water.

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Potential effects on rural economies of conversion to sustainable farming systems

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Abstract. *Conversions from conventional to sustainable farming systems could affect local rural economies either positively or negatively, by several means: changes in income of agricultural households; backward linkages to input supply firms; forward linkages to transportation, processing, and marketing firms; and changes in consumer expenditures by agricultural and other households. We estimated these effects for five local rural economies in South Dakota, representing different agroclimatic and population settlement patterns. Whole-farm economic models of case study conventional and sustainable farms in each area were used to estimate differences in input purchase and marketing patterns. We found declines in on-farm personal income (returns to farm labor and management) in four of the five case comparisons under a conversion to sustainable farming systems if organic price premiums are ignored; we found increases in three of five cases if applicable organic premiums are included. In all five study areas, total off-farm personal income drops in the portions of local economies connected to farming through backward linkages. It also drops in four of the five study areas in the portions of local economies connected through forward linkages if organic premiums are ignored (all five if organic premiums are included). However, net forward linkage effects are usually much smaller than net backward linkage effects, and on-farm personal income effects are substantially greater than either backward or forward off-farm linkage effects in most cases. The total (on- and off-farm) personal income effect of converting to sustainable systems is positive in only one area without organic premiums, and in one additional area with premiums. The ratio of total to on-farm personal income effects within local economies, considering only first round effects on backward- and forward-linked firms, averages 1.2 without organic premiums, or 0.6 with them. Taking account of more complete multiplier effects, which also consider changes in consumer expenditures and changes in expenditures for supplies by backward- and forward-linked firms, the average is 1.8 without organic premiums, or 0.8 with them. With more time for changes in sustainable production techniques and in the structure of farms and the rural economy, the overall economic effects of conversions to sustainable farming are likely to be more positive than our estimates.*

Keywords: sustainable agriculture, organic farming, rural economy, multiplier effects, forward linkages, backward linkages, net farm income

Introduction

Environmental and farm profitability concerns have stimulated major debate since the mid-1980s over the relative merits of "conventional" and "sustainable" farming systems in the United States. "Conventional" farming systems can be viewed as ones whose cropping patterns, tillage practices, and chemical fertilizer and pesticide application rates are typical for the area. "Sustainable" systems (often called "alternative", "low-input/sustainable agriculture" [LISA], "low-input", or "regenerative" systems), on the other hand, either eliminate or greatly reduce the use of chemical fertilizers and pesticides. They emphasize crop rotations, legumes, tillage practices, and cover crops to maintain soil fertility, control weeds, and prevent soil erosion. The debate has primarily been over the different farming systems' yields, farm profits, and environmental effects.

As debate and discussion continue to broaden, the role of sustainable agriculture in revitalization of rural areas is receiving increased attention. Critics often contend that converting to "sustainable" systems would harm rural economies, primarily because "sustainable" farmers would buy fewer inputs from local agricultural supply firms. Others suggest that sustainable agriculture may be a foundation on which successful rural communities of the future can be built (Hassebrook, 1990; Ikerd, 1990). This could happen if sustainable farming practices increase returns to skilled labor and management, and if new rural businesses emerge to serve the specialized needs of sustainable agriculture. Many issues need to be examined to determine which farming systems best serve the combined needs of farm families, rural communities, and the environment.

We report an empirical examination of some potential short term effects on local rural economies of a conversion from conventional to sustainable farming systems and practices, including effects on agricultural households and off-farm effects felt through forward and backward linkages. Case study "conventional" and "sustainable" farms in five different agroclimatic areas of South Dakota were used to generate data for the quantitative

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analysis. Later we discuss possible longer term implications of sustainable agriculture for rural communities that are not yet quantifiable.

Lockeretz (1989) examined some off-farm effects of the type treated here. That work drew on farm management budgets that others had developed in several parts of the U.S., including South Dakota budgets that we had developed using early research results from a South Dakota State University experiment station (Dobbs et al., 1987, 1988). The research reported here draws upon farm management data subsequently developed from actual operating sustainable farms in South Dakota. Also, whereas Lockeretz's article treated only "first-round" off-farm effects, we consider both first-round and more complete multiplier effects.

Case Study of Farm Comparisons

Case study sustainable farms in this analysis are part of a broad economic and policy study of sustainable agriculture in South Dakota. Detailed crop, livestock, and related economic information on twenty-two sustainable farms in different areas of South Dakota was collected through on-farm interviews in early 1989 (Taylor et al., 1989). Whole-farm economic analyses subsequently were done for the cropping systems of twelve of these farms (Becker et al., 1990). Effects of public policies on the relative profitability of sustainable and conventional farms have been examined, using five of those twelve sustainable farms as case studies (Dobbs et al., 1991a). These five farms also are used as cases for the analysis reported in this article; they represent particular types of sustainable farming systems in different agroclimatic areas in South Dakota (Figure 1). Corn and soybeans predominate in the south-central and east-central areas. Spring wheat is the principal crop in the northeast and northwest areas, and winter wheat is the primary cash crop in the southwest area. Each of the five farms incorporates some features in its sustainable system that differ from those of the other four; for example, the east-central sustainable farm has alfalfa as part of its rotation, whereas the south-central farm has sweet clover, although both farms are located in "corn-soybean" areas. Detailed information about the crop rotations, cultural practices, and costs and returns of these five case farms is found in Taylor et al. (1989) and Becker et al. (1990).

These five sustainable farms are compared with five conventional farms, one of which (in the east-central area) is an actual operating farm and four of which are "synthetic." Detailed longitudinal analysis of yields and economic returns on the east-central conventional and sustainable (actual operating) farms has been reported elsewhere (Dobbs et al., 1991b). For other areas of the state, we constructed hypothetical ("synthetic") conventional farms from various information sources, including the Agricultural Census, Cooperative Extension and Soil Conservation Service reports, and interviews with key informants. Details of the crop systems and cultural practices for the conventional farms are found in Cole and Dobbs (1990).

Brief descriptions of the case farms are as follows:

1. *East-central area.* The farms have approximately 700 to 800 crop acres. The conventional farm rotates corn and soybeans in a 2-year rotation, whereas the sustainable farm rotates corn, soybeans, alfalfa, and small grains (spring wheat and oats) in a 4-year rotation. Both farms have beef cattle and hogs.

2. *South-central area.* The sustainable farm has 260 crop acres and no livestock. Soybeans and spring wheat are the cash crops on the sustainable farm, and sweet clover is used as green manure on set-aside acres. The synthetic conventional farm is assumed to be of similar size and to grow primarily corn and soybeans, plus small amounts of oats and alfalfa.

3. *Northeast area.* The farms have approximately 750 to 800 crop acres. The sustainable farm has approximately one-fourth of its land each in spring wheat, alfalfa, summer fallow, and other crops (including soybeans, millet, and flax). It also has beef cattle. The synthetic conventional farm is assumed to have approximately one-third of its cropland in spring wheat, one-fifth in summer fallow, a total of one-third in corn, soybeans, and barley, and a small amount in alfalfa. It is assumed to have beef cattle.

4. *Northwest area.* The sustainable farm has approximately 900 crop acres, with approximately half in summer fallow each year, most of it in green manure sweet clover and some in forage sudan. Approximately 40 percent of the acreage is in spring wheat and oats; remaining cropland is planted to corn. This farm has a beef cow-calf operation. The synthetic conventional farm is assumed to fallow approximately half its cropland each year, but as "black" fallow, rather than the green manure cover crop fallow used on the sustainable farm. Approximately 40% of the conventional farm's cropland is assumed to be in spring wheat and barley, and a small amount in corn. Cattle are assumed to be part of the conventional farm operation.

5. *Southwest area.* The sustainable farm has approximately 2,600 crop acres, with approximately one-third each in winter wheat and summer fallow. Most of the remainder is in buckwheat and millet, with a small amount in alfalfa. This farm has a beef cow-calf operation. The synthetic conventional farm is assumed to be of similar size, and also to have approximately one-third of its cropland each in winter wheat and summer fallow. Most of the remainder is assumed to be in sorghum and oats, and some alfalfa. It is assumed to have cattle.

Permanent hay and pasture are not included in the crop acreages described for these case farms.

Brief overviews of the key features of the case farms in each area are shown in Tables 1 and 2. Grain production per 100 acres of cropland is greater on the conventional farms in all five areas (Table 1). (Cropland in Tables 1 and 2 includes farm program set-aside, fallow, and green manure, as well as harvested crops and rotated hay.) Hay production per 100 acres of crop land is higher for the sustainable farms in the east-central and northeast areas, but higher for the conventional

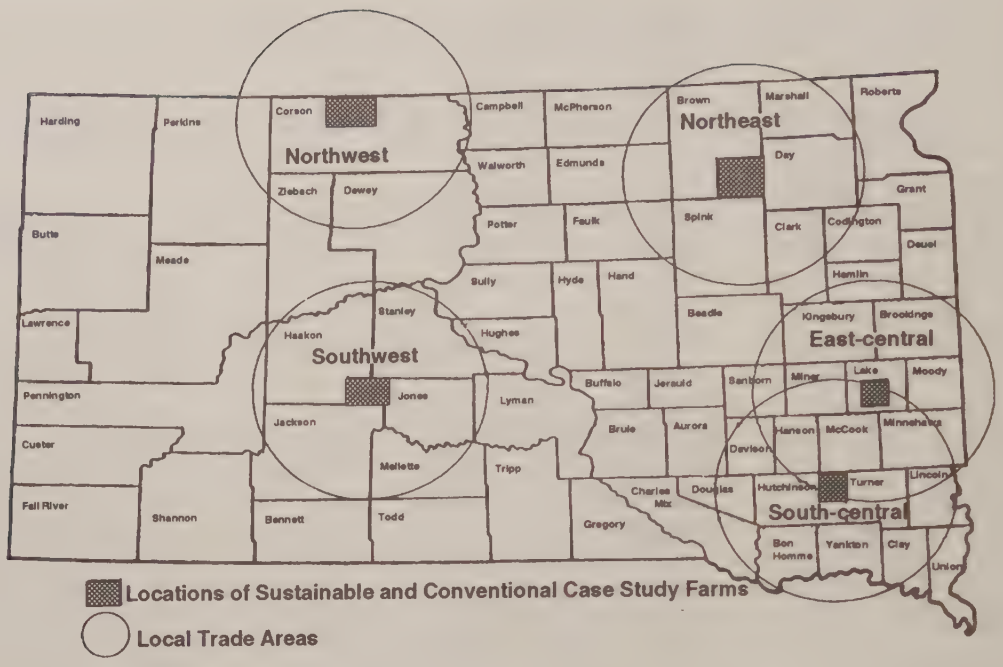

Figure 1. Locations of local trade areas and South Dakota case study farms.

farms in the south-central and southwest areas (Table 1); the south-central case sustainable farm did not have any hay. No production of hay is shown for either the sustainable or the conventional farm in the northwest area, because the alfalfa hay land there was considered more or less "permanent," that is, it is on land not included in the rest of the respective rotations. Thus, for purposes of analyzing the effects of changeovers from conventional to sustainable rotations and systems, it was not necessary to include that land in the analysis. Likewise, in all five areas, hay harvested from permanent grass or pasture was excluded.

As shown in Table 2, except in the northwest area, only the conventional case farms use commercial fertilizer. The commercial fertilizer used by the northwest case sustainable farm is an organic fertilizer of naturally mined trace minerals. The cost of commercial fertilizer per 100 acres of cropland is greater on that sustainable farm than on its conventional counterpart.

Of the case sustainable farms, only the east-central and the south-central farms use pesticides (Table 2). The east-central sustainable farm uses some herbicides on a small area. Some spring wheat is spot-sprayed with herbicides on the south-central sustainable farm.

Fuel and lubrication expenses are higher for the conventional farms than for the sustainable farms in all but the east-central area (Table 2). The differences range from 63% higher for the conventional farm in the northwest area to 30% lower for the conventional farm in the east-central area. Sustainable farms are often thought to use more tillage (primarily for weed control) and therefore more fuel. However, several factors contribute to overall fuel use per unit of cropland, including the mix of crops grown and the management of set-aside and fallow acres. In all but one case comparison, the combined result of these effects is lower fuel and lubrication expenses on sustainable than on conventional farms.

Table 1. Grain and hay production for sustainable and conventional farms, per 100 acres of cropland.

	South-central	East-central	Northeast	Northwest	Southwest
Grain (thou of bu)					
Sustainable	2,329	2,980	1,011	1,324	1,778
Conventional	5,196	5,417	2,390	1,424	2,184
Hay (tons)					
Sustainable	0	49	38	0	1
Conventional	26	36	22	0	11

Table 2. Selected expenses for sustainable and conventional farms ($ per 100 acres of cropland).

	South-central	East-central	Northeast	Northwest	Southwest
Commercial fertilizer					
Sustainable	0	0	0	450[1]	0
Conventional	979	1,247	786	392	335
Pesticides					
Sustainable	5	95	0	0	0
Conventional	510	1,767	589	112	70
Fuel and lubrication					
Sustainable	509	438	377	265	279
Conventional	531	306	410	433	369
Labor					
Sustainable	1,220	1,074	738	444	589
Conventional	1,225	728	821	705	619

[1]Organic fertilizer

Labor expenses show a similar pattern. They are higher on the conventional farms in four of the five areas (Table 2). The differences range from 59% higher for the conventional farm in the northwest area to 32% lower in the east-central area. The principal use of labor for crop production on South Dakota farms is to operate machinery. Machine time, as reflected in part by fuel and labor use, appears to be greater on the conventional farms in most cases. All labor is included in these comparisons, whether provided by the operator, the operator's family, or hired workers. We assume that all labor, including family labor, has "opportunity cost." These comparisons, including labor expense, do not cover livestock operations of either the sustainable or the conventional farms.

Agricultural Household and First-Round Off-farm Effects

The on-farm effect of conversion from conventional to sustainable farming systems is the change in net incomes of agricultural households. Agricultural households are defined here as farm proprietors and their families and hired laborers. Off-farm effects result from "backward" and "forward" linkages to the farm sector. These linkages are conceptualized in Figure 2.

Backward linkages involve farm input purchases from retail firms (e.g., purchases of commercial chemical fertilizers and pesticides), service firms (e.g., machinery repair purchases), and finance and insurance firms (e.g., interest payments to financial institutions). Net incomes change in the input sector because of increases or decreases in purchases; the net income changes are only a fraction of the total changes in purchases, however.

Similar net income changes occur from forward linkages when a switch to alternative farming systems causes a change in output. If output of some grains declines, for example, less grain may be stored and marketed by local elevators. We would then expect reduced profits and labor earnings by the elevators. Where hay output increases from a switch to sustainable systems, there could be additional local trucking of hay and increased profits for trucking firms.

The backward and forward linkage effects just described can be considered "first-round" off-farm effects. Later we treat additional effects on local net incomes that can result from changes in consumer purchases by agricultural households and by owners and workers in input and output sector firms.

Methods and Assumptions

Whole-farm budgets for the cropland portions of the case conventional and sustainable farms were compared to estimate first-round increases or decreases in purchases (backward linkages) and sales (forward linkages) associated with conversions to sustainable farming systems. Data from various sources were used to estimate the proportions of purchases made "locally", proportions of firms' receipts that translate into personal income, and so forth (Dobbs and Cole, 1991).

Local trade areas were specified for each of the five study areas by drawing a circle with a 50-mile radius from each pair of conventional and sustainable farms (Figure 1). This distance represents approximately a 1-hour drive for goods and services, depending on the roads to particular towns. These circular local trade areas encompass approximately the following numbers of towns, many of which are very small: south-central, 100; east-central, 100; northeast, 75; northwest, 45; and southwest, 30. South Dakota's largest city, Sioux Falls, is in the trade areas of both the south-central and east-central case farms. Aberdeen, the State's third largest city, is in the northeast circular trade area. The northwest and southwest trade areas, besides having fewer towns, have none anywhere near as large as Aberdeen or Sioux Falls.

Input purchases were categorized under one of three sectors: retail trade; service trade; and finance and insurance. We estimated the proportions of each input purchased locally in each area, considering natural barriers to transportation (such as rivers), towns and cities within and sur-

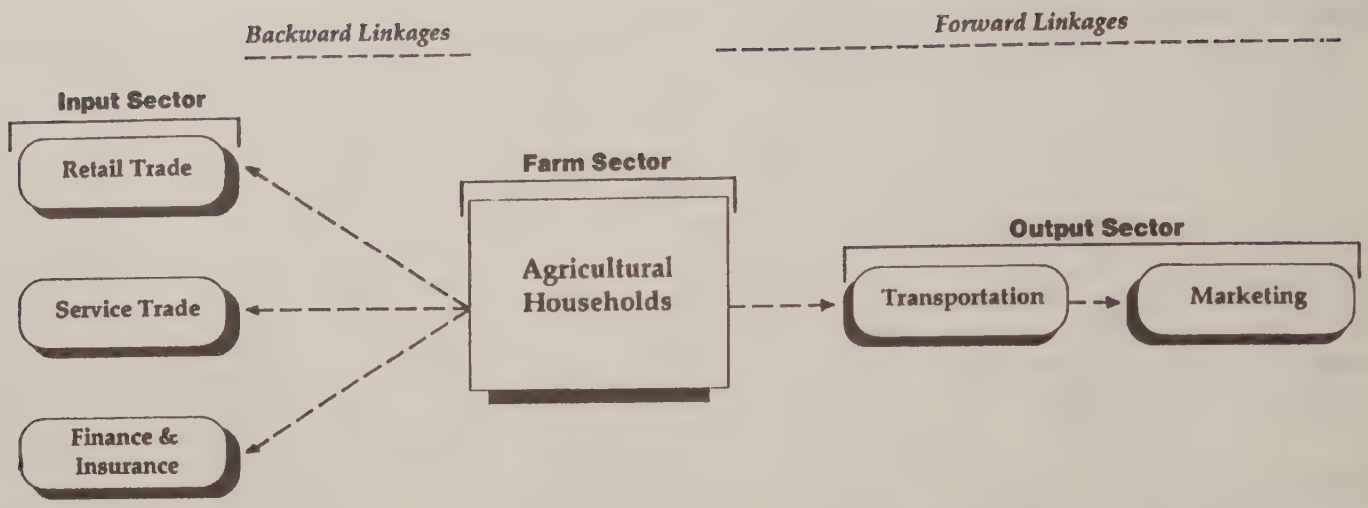

Figure 2. Conceptualization of conventional and sustainable agriculture effects on local economies.

rounding each trade area, and typical travel distances for particular kinds of goods and services. We used evidence from North Dakota and South Dakota (Dobbs, 1979; Goreham et al., 1986; Leistritz et al., 1987; Owens and Vangsness, 1973) in making our estimates for each trade area. We estimated, for example, that purchases of commercial fertilizer (a retail trade item) would be 80% local in the south-central area and 70% local in the southwest area. In the finance and insurance sector, we estimated that interest expense for operating loans would be 95% and 85% local in the south-central and southwest areas, respectively.

Similar estimates were made on the marketing (forward linkage) side. For example, in the east-central area, we estimated that 95% of the grain marketed "conventionally" is delivered to local elevators, that none of the grain presently marketed "organically" goes to local elevators or other marketing agents, and that 95% of the hay that is sold is hauled by local truckers.

Besides the proportions of input purchases and crop sales made locally, estimates were needed for proportions of receipts in each sector that constitute personal income, where personal income consists of profits, wages, and other employee compensation. Evidence from the following sources was reviewed in arriving at these estimates: Dobbs (1979), Devino et al. (1987), Leistritz et al. (1989), and U.S. Dept. of Commerce (1977, 1989a,b,c,d). Our estimates of the proportions of receipts that constitute personal income, by sector, are: retail trade, 0.15; service trade, 0.22; finance and insurance, 0.20; agricultural households, 1.00; country elevators, 0.05; and trucking industry, 0.20. A coefficient of 0.15 for commercial fertilizer (part of the retail trade sector), means that 15% of a local agricultural supply firm's receipts from fertilizer sales was assumed to constitute profits and employee wages and other compensation.

In examining first-round effects, it is not unrealistic to use single estimates of the proportions of receipts that constitute personal income for each group of inputs (e.g., retail trade sector inputs) or outputs (e.g., grain). However, when we examine more complete multiplier effects involving subsequent rounds of expenditure, we must make distinct estimates for input types within different trade sectors and for different trade areas. That will be explained later, in the section on more complete multiplier effects.

Results

Results presented in this paper should be interpreted as case findings for different types of sustainable farming systems in rural areas of varying population densities. We have deliberately avoided presenting results here on an area (county or multicounty) basis, because it would be speculative to imply that the case findings are statistically representative. Nevertheless, case findings can provide insights on the types and magnitudes (per unit of cropland) of economic effects that might result from changeovers to particular farming systems.

Table 3 shows on-farm and first-round off-farm backward and forward linkage effects on personal income from converting 100 acres from conventional to sustainable practices in each of the five South Dakota study areas. Organic premiums that four of the five case sustainable farmers received for some of their grain are excluded in the baseline analysis, but are accounted for in the figures shown in parentheses. Baseline effects range from a positive $29 per 100 acres in the northwest area to a negative $5,469 in the east-central area. When organic premiums are included, effects range from a positive $361 to a negative $5,010.

Baseline on-farm agricultural household income for the case sustainable farm in the northwest area is higher than for the comparable conventional farm, even without organic premiums (Table 3). There, the positive agricultural household effect more than offsets the negative first-round backward and forward linkage effects. When organic premiums are included, on-farm agricultural household incomes for the sustainable farms in the northeast and southwest areas also exceed those of the comparable conventional

Table 3. Summary of on-farm and first-round off-farm effects on rural economies: Changes in personal income ($ per 100 acres).[1]

	South-central	East-central	Northeast	Northwest	Southwest
Backward Linkage Effects					
Retail trade	-343	-481	-273	-25	-43
Service trade	-11	29	-11	-18	5
Finance and insurance	-62	-36	-89	-29	-22
Subtotal[2]	-417	-488	-373	-71	-61
On-farm Effect (Agricultural Households)					
Subtotal	-1,499	-4,562	-442	116	-284
		(-4,062)	(358)	(516)	(316)
Forward Linkage Effects					
Country Elevators	-92	-424	-148	-15	16
		(-465)	(-262)	(-84)	(-37)
Trucking Industry	-10	5	6	0	-4
Subtotal[2]	-102	-419	-142	-15	13
		(-461)	(-256)	(-84)	(-41)
TOTAL[2]	-2,018	-5,469	-957	29	-332
		(-5,010)	(-271)	(361)	(215)
Ratio of Total					
Effect to	1.35	1.20	2.17	0.25	1.17
On-farm Effect		(1.23)	(-0.76)	(0.70)	(0.68)

[1]Figures in parenthesis result when organic premiums are included in the analysis. The south-central sustainable farm has no organic sales.

[2]Because of rounding to whole dollars, some totals differ from the sum of the detailed numbers.

farms. In the southwest, the increased agricultural household income attributable to organic premiums more than offsets the negative off-farm effects (Table 3).

In Table 3, the forward linkage effects are more negative, or less positive, when organic premiums are included. This is because initial points of sale for organic grains currently are all outside all five local trade areas, not at local country elevators, which is where most conventional grain is delivered.

The retail trade sector is the backward-linked sector that is harmed the most by the conversion to sustainable practices in most areas. Interestingly, in two areas (the east-central and the southwest), the service trade sector experiences a slight increase in personal income because of increased machinery repair expenditures.

Net forward linkage personal income effects are relatively small (when organic premiums are ignored) in comparison to net backward linkage effects, except in the east-central area, where the backward effects are a negative $488 per 100 acres and the forward effects are a negative $419 per 100 acres (Table 3). In all areas, agricultural household effects are greater than either the backward-linked or the forward-linked effects (especially in the south-central, east-central, and southwest cases) when organic premiums are ignored, and in all but the northeast area are greater than the two combined. Retail trade effects are substantially greater than other backward-linked effects in most areas, and country elevator effects substantially exceed trucking industry effects in all areas.

The ratios of total to on-farm effects in Table 3 range from 0.25 to 2.17 when organic premiums are ignored. Including the organic premiums causes the ratio for the northeast area to change from positive to negative (from +2.17 to -0.76). This is because on-farm effects become positive, even though total effects remain negative. The ratio of total to on-farm personal income effects averages 1.23 when organic premiums are excluded and 0.64 when they are included.

More Complete Multiplier Effects

The foregoing effects cover first-round local effects on sectors linked directly to the farm sector. Additional local effects can occur from changes in consumer expenditures by farm households, in purchases of supplies by forward- and backward-linked firms, and in purchases of consumer goods by owners and employees of firms affected by first-round expenditures and subsequent rounds of expenditures. By including these effects on per-

sonal income, in addition to the agricultural household and first-round effects, more complete potential multiplier effects can be accounted for.

The approach used followed that of Darling (1990), in which economic base-type multipliers are used; similar methods are explained in more detail in Hustedde et al. (1984). We have adapted those generalized methods of assessing the effects of agriculture on local economies to the sustainable agriculture issue analyzed in this article. Our procedure, which is documented in Dobbs and Cole (1991), involves estimating on-farm and off-farm effects on personal income, where on-farm effects are defined as in the previous section. Off-farm effects include induced, indirect backward linkage, and indirect forward linkage effects.

Indirect effects are defined by Darling (1990) as follows:

$$\text{Indirect effects} = OB \times PCL_f \times PSY$$

where

OB = farmers' nonpayroll operating budgets,

PCL_f = the proportion of farmers' operating budgets spent locally, and

PSY = the proportion of consumption spending locally that becomes local income.

PCL_f values used here were the same as those used in our analysis of first-round off-farm effects (e.g., 0.70 for fertilizer purchases in the southwest area).

PSY values take into account effects on local income from all rounds of expenditure, not just the first round, to the extent that portions of each round remain within the local trade area. Estimates of PSYs for the various input and marketing sub-sectors in each of the five trade areas were made, keeping in mind values suggested by Darling (1990) and other sources of related information (Dobbs and Cole, 1991; U.S. Dept. of Commerce, 1977). Unlike when only first-round effects were examined, it was necessary here to use distinct PSY estimates for different input types within each trade sector and for different trade areas. This is because "leakage" from subsequent rounds of expenditure is greater for some inputs than for others within the same sector (e.g., for fertilizer, as compared to grain storage, within the retail trade sector) and for some trade areas than for others (e.g., for the southwest area, as compared to the south-central area).

As an example, we assumed a PSY value of 0.25 for the fertilizer sub-sector in southwest South Dakota. The fertilizer portion of a farmer's operating budget in southwest South Dakota decreases by $335.15 per 100 acres on converting to the sustainable system. Using the above formula, we calculated the related backward linkage indirect change in personal income:

$$-335.15 \times 0.70 \times 0.25 = -\$58.65$$

The estimated total for all indirect backward linkage effects in the southwest area is approximately -$98 per 100 acres.

Similar procedures were used to calculate forward linkage indirect off-farm effects. PML_f was substituted for PCL_f in the above formula, where PML_f stands for the proportion of farm product trucked or marketed by local firms. Values for PML_f were the same as those used in the analysis of first-round secondary effects. Again, using the southwest as an example, country elevator changes in receipts (positive $378) were multiplied by the appropriate PML_f (0.85) and then times the appropriate PSY (0.06). The estimated increase in personal income from increased grain sale receipts for local elevators (and consequent increases in related input and consumer purchases) was approximately $19 ($378 × 0.85 × 0.06). Total indirect forward linkage effects, combining elevator and trucking industry effects, were estimated to be approximately $14 per 100 acres in the southwest local trade area.

Agricultural households can be expected to increase (decrease) consumer spending when their personal incomes rise (fall) because of a change from conventional to sustainable systems. The changes in local area off-farm personal income that result from these increases or decreases are called induced effects. The formula for induced effects is as follows (modified from Darling, 1990):

$$\text{Induced effects} = AG/(1-PCL_h \times PSY) - AG$$

where

AG = personal income effects on agricultural households, and

PCL_h = the proportion of new household income that will be spent locally,

and PSY has the same meaning as in the first formula. Darling presents PCL_h data for Kansas counties. We used data for Kansas counties that appear similar to South Dakota areas examined in our study, and information on the number and sizes of towns and cities in and near the South Dakota local trade areas, to make judgments about appropriate PCL_h coefficients. We assumed PCL_h values of 0.85 in the south-central and east-central areas, 0.80 in the northeast area, and 0.60 in the northwest and southwest areas. Since agricultural household personal income effects (changes in labor and management income) were a negative $283.62 in the southwest area, the calculation for induced personal income effects in that area was:

$$-283.62/(1-.60 \times .30) - (-283.62)$$
$$= -283.62/0.82 + 283.62$$
$$= -\$62$$

All off-farm effects (induced, indirect backward linkage, and indirect forward linkage) together are estimated to total a negative approximately $146 per 100 acres in the southwest area, when organic premiums are ignored. Personal income in the southwest area is estimated to decline by approximately $430 per 100 acres, when all on-farm and off-farm effects of converting 100 acres from conventional to sustainable rotations and practices are combined and when organic premiums are ignored. The ratio of estimated total to on-farm effects is 1.52.

On-farm and off-farm personal income effects for all five areas are summarized in Table 4. As with Table 3, baseline results in this table do not take account of organic premiums, whereas data in parentheses do. Total effects per 100 acres are greatest in

Table 4. Summary of on-farm and more complete multiplier off-farm effects on rural economies: Changes in personal income ($ per 100 acres).[1]

South-Central Area			
1. On-farm Effect		-1,499	
2. Off-farm Effects			
a. Induced effects, agricultural households	-772		
b. Indirect effects, backward linkages	-994		
c. Indirect effects, forward linkages	-168		
Subtotal[2]		-1,934	
TOTAL[2]		-3,433	
Ratio of Total Effect to On-Farm Effect = (-3,433)/(-1,499) = 2.29			
East-Central Area			
1. On-farm Effect		-4,562	(-4,062)
2. Off-farm Effects			
a. Induced effects, agricultural households	-2,350		(-2,092)
b. Indirect effects, backward linkages	-1,177		
c. Indirect effects, forward linkages	-669		(-735)
Subtotal[2]		-4,196	(-4,004)
TOTAL[2]		-8,757	(-8,066)
Ratio of Total Effect to On-Farm Effect = (-8,757)/(-4,562) = 1.92			(1.99)
Northeast Area			
1. On-farm Effect		-442	(358)
2. Off-farm Effects			
a. Induced effects, agricultural households	-172		(139)
b. Indirect effects, backward linkages	-715		
c. Indirect effects, forward linkages	-197		(-357)
Subtotal[2]		-1,084	(-939)
TOTAL[2]		-1,525	(-574)
Ratio of Total Effect to On-Farm Effect = (-1,525)/(-442) = 3.45			(-1.60)
Northwest Area			
1. On-farm Effect		116	(516)
2. Off-farm Effects			
a. Induced effects, agricultural households	25		(113)
b. Indirect effects, backward linkages	-100		
c. Indirect effects, forward linkages	-18		(-101)
Subtotal[2]		-93	(88)
TOTAL[2]		22	(428)
Ratio of Total Effect to On-Farm Effect = 22/116 = 0.19			(0.83)

(continued)

[1]Figures in parenthesis result when organic premiums are included in the analysis. The south-central sustainable farm had no organic sales.
[2]Because of rounding to whole dollars, some totals differ from the sum of the detailed numbers.

Table 4. Summary of on-farm and more complete multiplier off-farm effects on rural economies: Changes in personal income ($ per 100 acres).[1] (continued)

Southwest Area			
1. On-farm Effect		-284	(316)
2. Off-farm Effects			
a. Induced effects, agricultural households	-62		(69)
b. Indirect effects, backward linkages	-98		
c. Indirect effects, forward linkages	14		(-50)
Subtotal[2]		-146	(-79)
TOTAL[2]		-430	(238)
Ratio of Total Effect to On-Farm Effect = (-430)/(-284) = 1.52			(0.75)

[1]Figures in parenthesis result when organic premiums are included in the analysis. The south-central sustainable farm had no organic sales.

[2]Because of rounding to whole dollars, some totals differ from the sum of the detailed numbers.

the east-central and south-central case comparisons. Net on-farm and off-farm personal income effects of conversions to sustainable farming practices are negative when organic premiums are excluded, except in the northwest, where positive on-farm effects more than offset negative off-farm effects. When organic premiums are included, the southwest case comparison also shows a positive overall effect on area personal incomes.

The ratio of total to on-farm effects ranges from 0.19 in the northwest to 3.45 in the northeast, when organic premiums are ignored. The ratio for the northeast area becomes negative (-1.60) when organic premiums are taken into account. With organic premiums, the ratio ranges from -1.60 to 2.29.

Discussion

We have reported certain quantifiable rural economy effects of conversions from conventional to sustainable rotations and practices. Effects were broken into agricultural household, backward linkage, and forward linkage effects on personal income. Effects on agricultural household personal income (consisting of labor charges and net income to management) generally were the biggest (Tables 3 and 4). This means that the principal income effect on rural economies depends upon how remunerative the sustainable practices are to farmers and farm workers, compared to conventional practices. To the extent off-farm effects on local rural economies are important, the effects of backward linkages are usually much greater than those of forward linkages. Overall rural economy effects were negative in three of five South Dakota case farm comparisons when organic premiums were included, and in four of five when they were excluded. The ratio of total to on-farm effects is smaller when organic premiums are included because organic premiums affect on-farm incomes more than local off-farm incomes and because the off-farm forward-linked local income effects are negative.

The possible effects on rural economies of farms converting to sustainable agricultural practices that have been estimated quantitatively and presented in this article are, to some extent, short-term in nature. In the longer-term, various on- and off-farm adjustments might alter the effects we have estimated, and might cause other effects.

For example, our analyses have ignored any differences in size between conventional and sustainable farms that may exist at present or in the future. Because some people believe that sustainable farms require more intensive management, one might expect sustainable farms to be smaller, on average, than conventional farms. Operators of large farms may purchase more of their inputs in volume, at discount prices, from more distant markets. They also may be more likely to truck their grain directly to large elevators or terminals outside the local trade area. Also, to the extent that net farm income is more concentrated with conventional agriculture, the coefficients for induced local off-farm personal income effects could be lower than for sustainable agriculture if the concentrated income increases the consumption of luxuries obtained outside the local area. If such differences exist, some coefficients used in our analyses would need to be altered, to reflect more "leakage" from the rural economy with large conventional farms.

Livestock have been accounted for only implicitly in this article. It is often asserted that sustainable farms are more likely to have livestock than conventional farms because sustainable farmers want manure to meet part of their soil fertility needs and because they frequently use forage legumes in their crop rotations. If livestock are present, this provides potential for greater agricultural household income, but it also has the potential for greater losses. In analyses we have conducted of nine sustainable farms in South Dakota having both crop and livestock enterprises, hogs were positive contributors to net farm income and beef cattle were negative contributors when baseline livestock prices (prices "expected" for 1988) were used (Taylor et al., 1990). The contribution of livestock to on-farm income varies with market prices, of course, and we have conducted sensitivity analyses to account for that. Livestock enterprises also have backward and forward linkage effects on local personal income. Comparison of the contributions of livestock on both sustainable and conventional farms to on- and off-farm

personal incomes was beyond the scope of the present study, however.

We can speculate briefly here on some possible implications of including livestock in a rural economy analysis. In rural areas with weak backward and forward linkages, as in much of the northern Great Plains, the principal local income effect of including livestock is likely to be the on-farm effect. That is what we found in our crop analysis. Hence, if a sustainable crop-livestock system replaces a conventional crops-only system or a conventional crop-livestock system, and if the on-farm personal income effect is substantially positive, then the total personal income effect also is likely to be positive.

The presence of livestock and associated manure can reduce the need for some purchased fertilizer. Livestock do create added demands for some off-farm inputs, such as feed additives and veterinary services. However, sustainable farmers are likely to use fewer such purchased inputs per head of livestock than conventional livestock producers. To the extent livestock go through local auction markets and, possibly, through local packing plants, crop-livestock systems are likely to exhibit greater positive forward-linked personal income effects than crops-only systems. The net forward-linked effect depends on the comparative local value added through livestock and grain, respectively, since crops-only systems tend to produce more grain than do comparably sized crop-livestock systems. If conventional crop-livestock systems are replaced by sustainable crop-livestock systems in which sustainable producers depend on organic or other special-label livestock product markets, forward-linked local personal income effects are likely to be negative unless a specialized local processor-marketer is involved.

As research on "sustainable" agriculture intensifies over the next few years, the relative economic profitability of sustainable systems is likely to increase. Changes in Federal farm programs and energy prices are also likely to increase the relative profitability of sustainable farming systems (Dobbs et al., 1991a,b). Although organic premiums could substantially decline if large numbers of producers enter organic markets, a shift toward sustainable farming practices could cause grain prices to rise overall, because less cropland would be in grain, and per acre yields of some crops, such as corn, could be lower. (Conversely, forage prices could fall.) These and other factors are likely to change the mix of available "sustainable" practices and to change the relative profitability of sustainable and conventional practices. Both on-farm incomes and induced off-farm incomes would be affected by those changes. Rural economy effects of conversions from conventional to sustainable agricultural practices are likely to appear more positive (or less negative) than in the short-term analysis of this article.

In a longer term and more dynamic context, other rural economy changes are likely to accompany conversions to sustainable agriculture practices. Some agricultural input suppliers may provide more information services, such as integrated pest management, fertility management, and specialty crop management, not just physical products such as chemical fertilizers and pesticides. Thus, as demands for some types of conventional agricultural inputs decline, demands for other, less conventional inputs may increase. Likewise, as farmers diversify into other crops as they adopt sustainable rotations, the demand for new and different types of local marketing facilities, machinery, and services is likely to expand.

It is difficult to identify precisely all the changes that might occur in rural economies if we move to more sustainable farming practices over the next few decades, and it is even harder to quantify these changes. It is important to quantify the short-term changes analyzed in this article, to understand the adjustments in the rural economy that may be involved in a transition to sustainable agriculture practices. However, we must keep in mind that other changes would probably occur too, many of which may be beneficial to rural economies.

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INSTITUTE NEWS

IAA Board Approves New Policy Program at Mid-Year Meeting

At its mid-year meeting on September 12 in Burlington, Vermont, IAA's Board of Directors approved an expanded program of policy analysis, original research, and outreach to be undertaken by the Institute over the next several years. The new program responds to the view of the Board, and the alternative agriculture community, that a substantial increase in economic, technical, and political analysis is needed to effectively inform the public debate expected to accompany the development of the 1995 farm bill.

In a related matter, the Board chose to focus IAA's 10th annual conference on "Alternative Agriculture Policy: A New Time to Choose." The conference will revisit two USDA landmark studies--**A Time to Choose**, published in 1981, and **Report and Recommendations on Organic Farming**, published in 1980. The one-day conference, scheduled for March 1, 1993, in Washington, DC, will examine developments in the structure of agriculture, agricultural research and education, and federal policies of the past decade to better understand alternative agriculture policy issues and options in the 1995 farm bill debate and beyond.

The Board also elected Dr. John C. Gordon, Pinchot Professor of Forestry at Yale University, to a three-year term on the board of directors. Dr. Gordon was Dean of the School of Forestry and Environmental Studies at Yale for the past ten years. He will replace Maureen Hinkle of the National Audubon Society, whose term expires in March of 1993. Dr. Gordon brings to the Board an extraordinary breadth of knowledge and experience in natural resource management, university administration, research and education, and organizational management and development. The Board also extended its deepest gratitude to Maureen Hinkle for her dedicated service as a board member during the past six years, and for her faithful commitment to alternative agriculture.

In other business, the Board heard a report by a Washington, DC-based management consulting group which had been engaged by IAA to help it develop a comprehensive strategic plan for the years ahead.

Anderson, Hornick, and Weil Named to AJAA Editorial Board

Dr. Molly D. Anderson, Dr. Sharon Hornick, and Dr. Raymond R. Weil have accepted the Institute's invitation to join the Editorial Board of the AJAA.

Dr. Anderson is presently a research assistant professor in the School of Nutrition at Tufts University in Medford, Massachusetts. Her research has dealt mainly with agricultural research policy and with on-farm research as a means of furthering agricultural sustainability. Before joining Tufts, Dr. Anderson coordinated a demonstration farm project and studied low-input farmers in North Carolina. She holds a Ph.D. in Ecology from the University of North Carolina in Chapel Hill, North Carolina, and is co-author of a forthcoming book, **Alternative Approaches to Agricultural Research**.

Dr. Sharon B. Hornick is a soil scientist with the Soil-Microbial Systems Laboratory in the Agricultural Research Service of the U. S. Department of Agriculture, at Beltsville, Maryland. Since joining the USDA in 1977, she has had a number of special assignments, including serving as an associate professor of human nutrition at the University of Maryland in College Park, Maryland, and as a soil scientist with the U. S. Environmental Protection Agency. A consultant and advisor to

numerous environmental research and technology projects, Dr. Hornick has authored or co-authored fifty articles and reports on sustainable agriculture issues such as the use of organic wastes and crop residues. She holds a Ph.D. degree in agronomy from the Pennsylvania State University.

Dr. Raymond Weil is a professor in the Agronomy Department at the University of Maryland where he teaches and does research in soil and environmental science. Listed in **Who's Who in Science and Engineering** (1992), he has done extensive research and writing on soil management for sustainable agriculture, water quality impacts of low-input farming systems, and production practices such as relay cropping. Dr. Weil has a Ph.D. in soil fertility and ecology from the Virginia Polytechnic Institute in Blacksburg, Virginia. He has served as a lecturer in soil science at the University of Malawi, a Peace Corps volunteer in Ethiopia, and a farm manager with the National Sharecropper's Fund in North Carolina.

Bezdicek Named Director of WSU's Sustainable Ag Center

David F. Bezdicek, a member of the IAA's Board of Directors and the **American Journal of Alternative Agriculture's** Editorial Board, has been named Director of the Washington State University Center for Sustaining Agriculture and Natural Resources.

Bezdicek, a WSU soil microbiologist, is a nationally recognized authority on research in sustainable agriculture and natural resources. Under his direction, the center will concentrate on the viability of Washington agriculture while protecting soil, air, and water.

The center will also develop an ecological agricultural model that favors diverse cropping systems, biological pest control, and community and farm-based decision-making.

Sampson Receives Award

R. Neil Sampson, a member of the IAA's President's Council, has been honored by the Soil and Water Conservation Society with its highest honor, the Hugh Hammond Bennett Award. The award is given to no more than one individual annually in recognition of distinguished service and international accomplishments in land and water conservation.

Sampson received the award for his many contributions to the soil and water conservation movement as an employee of the Soil Conservation Service, as executive vice president of the National Association of Conservation Districts, and as executive vice president of American Forests (formerly American Forestry Association).

The award, presented to Sampson at the SWCS's 47th annual meeting in Baltimore, is named after the "father of soil conservation" in the United States and a founder of SWCS.

Fellowships in Honor of Berg Launched

Fellowships for the first annual Norman A. and Ruth A. Berg forum on public conservation policy were announced by the Soil and Water Conservation Society in July, 1992.

The inaugural forum was a special feature of the Society's 47th Annual Meeting in Baltimore in August, 1992.

The Fellowship Program was established with the support of Kenneth and Frances Robinson Novak in honor of Berg, a member of the IAA's President's Council, and his wife, Ruth.

Berg, who serves as the Washington, D.C., representative of SWCS and as Senior Advisor to the American Farmland Trust, has a distinguished 51-year career in soil and water conservation. He spent 39 years with the USDA's Soil Conservation Service, including three years as the agency's chief.

USDA Behind Schedule on Minor Crop Pesticide Work, Says GAO

The USDA "has been slow to respond" to concerns about the availability of pesticides for use on minor crops, and will not complete the research and analysis necessary to support the registration and reregistration of high-priority pesticides for use on minor crops by the 1997 deadline, according to a report by the U.S. General Accounting Office.

The report, prepared for U.S. Rep. E. (Kika) de la Garza, Chairman of the House Committee on Agriculture, also examines if the funds allocated for the Interregional Research Project No. 4 (IR-4) have been used effectively. Copies of "Pesticides: USDA's Research to Support Registration of Pesticides for Minor Crops" (GAO/RCED-92-190BR), are available from U.S. GAO, P.O. Box 6015, Gaithersburg, MD 20877; (202) 275-6241.

Farmers, New York City Agree on Plan to Save Reservoirs

New York City officials and farmers in the Catskill Mountains and lower Hudson Valley recently reached an agreement to reduce agricultural pollution of the city's reservoirs through voluntary measures far less strict than the mandatory controls the city proposed two years ago.

The pact, one of few in the country attempting to rely on voluntary measures to curb water pollution, will be tailored to each individual farm and put into effect over the next eight years. It also calls for the city to spend $3.4 million providing farmers with technical advice and capital improvements to reduce agricultural contaminants and improve their agricultural methods. As a result, the city will be able to avoid not only enacting tougher mandatory restrictions that would have placed financial burdens on farmers, but also building a $4 billion filtration system.

A perspective on the economic impacts of reducing agricultural chemical use

Linda K. Lee

Abstract. *Adoption of agricultural practices that reduce or eliminate chemical use creates tradeoffs among yields and output, production costs and net income at the farm level. If widespread adoption is to occur, potential improvements in human health and the environment from reduced chemical use must be weighed against effects on aggregate farm income and consumer food prices. At present, these tradeoffs are subject to considerable debate.*

I review available farm level and aggregate economic studies of reductions in total agricultural chemical use. At the farm level, available studies suggest that organic and low-input farming systems result in declines in per acre yields and in lower net returns than most conventional farming systems, although the studies do indicate that net returns for the two systems can be comparable under some conditions. Several studies suggest that low-input systems perform well with respect to risk criteria. I also discuss the potential influence of government programs on the profitability of some low-input farming systems.

All aggregate economic models conclude that widespread adoption of organic farming would result in decreased yields, decreased aggregate output, increased farm income, and large increases in consumer prices. These models have limitations, however. Recommendations are made for further economic research of the impacts of reducing agricultural chemical use at both the farm and aggregate levels.

Key words: low-input agriculture, organic agriculture

Concern over the human health and environmental consequences of conventional agricultural production practices recently has increased. Reports of contamination of food and drinking water wells by agricultural chemicals have helped to fuel a reexamination of the consequences of chemically intensive agricultural production (Nielsen and Lee, 1987; Natural Resources Defense Council, 1989). Although the evidence about both the contamination process and the health and environmental consequences of agricultural chemicals is still emerging, various policies have been proposed or enacted that ultimately could reduce agrichemical use by farmers. Pesticide bans, wellhead protection proposals, and potential liability for agricultural chemicals found in the environment could limit agrichemical use in vulnerable areas. Interest in low-input or alternative agriculture has increased in response to food safety issues, as well as groundwater quality and other environmental concerns.

Adoption of agricultural practices and systems that reduce or eliminate chemical use creates tradeoffs among yields and output, production costs and net income at the farm level. If widespread adoption is to occur, potential improvements in human health and the environment from reduced chemical use must be weighed against effects on aggregate farm income and consumer food prices. At present, these tradeoffs are subject to considerable debate. A recent report suggesting that alternative agriculture can be productive and profitable for farmers under some circumstances has generated varied responses within the scientific and agricultural community (National Research Council, 1989; Council for Agricultural Science and Technology, 1990).

This paper reviews available farm level and aggregate economic studies of reductions in total agricultural chemical use. I identify tradeoffs among agricultural yields, production costs, farm income, and consumer food prices, and quantify them where possible. I report gaps in existing research and make recommendations for future work.

Environmental and Economic Implications of Agricultural Chemical Reductions

Various terms are used to describe agricultural systems that reduce chemical input use, including alternative, low-input, and organic agriculture. Organic farming in most studies refers to farming without chemicals, including commercial fertilizers. Low-input and alternative systems are commonly used to refer to systems that reduce the use of purchased chemical inputs, but there are many individual definitions (Schaller, 1990). In this paper, the terms low-input and alternative agriculture are used interchangeably and are distinct from organic agriculture.

Because it often is difficult to document the linkages between changes in agricultural production practices and improvement in human health and the environment, the concept of input management to reduce

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unwanted outputs such as groundwater contamination has emerged (Weinberg, 1990). It assumes that reductions in chemical applications ultimately will mean less movement of chemicals to groundwater, surface water, and the atmosphere, and lower residues in food. Most economic research on practices or systems that reduce or eliminate the use of purchased inputs such as commercial pesticides and fertilizers has not directly linked chemical use changes with environmental indicators, but has assumed that environmental and human health improvements will occur from reductions in chemical use. A recent report suggests that this failure to account explicitly for environmental damages when analyzing low-input systems has seriously distorted the economic comparisons of low-input and conventional agricultural production systems (Faeth et al., 1991).

Analyses of the economics of adoption of low-input agricultural systems have focused on both farm level and aggregate tradeoffs. At the farm level, economic incentives for adoption depend on changes in yields, variable costs of production, and the relative impacts of both on net returns. On a larger scale, yield and cost data become key inputs to sectoral models that examine relationships among aggregate output, farm income, and consumer food prices. Studies of both types are limited because funding and institutional incentives have only recently stimulated increased research on the economics of low-input agricultural adoption. However, there is some research that allows a tentative analysis of the economic tradeoffs associated with adoption of low-input agricultural systems. The following sections review farm and aggregate level studies of the economic implications of low-input adoption and summarize tradeoffs.

Review of Farm Level Economic Analysis of Low-Input Agriculture

Farm level studies of the economics of adopting alternative agriculture can be classified into several categories: farm surveys, field studies, and case studies. Each category is discussed below.

Farm survey data

Several farm surveys were conducted in the late 1970s in an attempt to compare the performance of conventional and organic farmers (Table 1). Perhaps the most publicized were several surveys by a group of scientists at Washington University. Between 1974 and 1978 this group surveyed organic and conventional crop-livestock farmers in the Corn Belt (Klepper et al., 1977; Shearer et al., 1981). In 1974-76, they studied 14 matched pairs of organic and conventional Corn Belt farms. In 1977 and 1978, 23 and 19 organic farms, respectively, were surveyed by this group. These surveys were summarized as suggesting that organic farming could be as profitable or even more profitable than conventional farming, particularly during dry years such as 1974 and 1977, when growing conditions were unfavorable (Lockeretz et al., 1981). Under these conditions, lower gross production per unit of cropland on organic farms was largely offset by comparable reductions in operating expenses. Under more favorable growing conditions in 1978, conventional farms outperformed the organic farms.

Data on crop yields for organic farms in these studies were obtained from farmer estimates. The group also conducted field measurements to attempt to corroborate farmer's yield reports, and found that measured yields were very similar to reported yields (Lockeretz et al., 1980). Overall, these studies suggested that under certain growing conditions, organic crop-livestock farmers in the Corn Belt could compete successfully with conventional farmers. Some verification of this conclusion was obtained with a 10 year follow-up survey in 1987 of 174 organic farms first surveyed in 1977. The follow-up found that most farmers in the original 1977 sample (55%) were still farming in 1987 (Lockeretz and Madden, 1987). Because many of the original farmers could not be reached or had left farming during the 1980s, a complete comparison between the two groups was not possible. However, for the subset that could be surveyed again in 1987, only about 13% of the organic farmers had converted to conventional farming by 1987. Many organic farmers apparently were able to survive during a period of farm financial stress in the Corn Belt.

Other surveys conducted during this period reported varying yield differentials with organic farming, but most reported lower average profits for the organic farmers. These surveys, which are summarized in Table 1, relied on farmers to report yields in comparison to comparable or neighboring farms. Consequently, reporting inaccuracy is a potential problem with these studies, as is the limited number of farms surveyed. The farm surveys I reviewed did not control for possible soil quality differences between organic farmers and their neighbors, which weakens the comparisons. Also, yield effects that occur over time, particularly in new organic enterprises, were not considered. With these limitations recognized, the organic surveys conducted in the 1970s suggest that yields for most surveyed crops would likely decline under organic production methods. These yield declines, coupled with declines in gross production per unit of cropland because of rotations of cash crops with hay and forage crops, mean that, even with lower variable costs, net profits for organic farming would be lower than for conventional systems. An exception occurs during dry years, when organic farming systems can perform as well as conventional systems.

Field studies

Potential biases in the survey approach have led to economic analyses of the farm level profitability of low-input or organic farming systems using experiment station or other research field data. These field data are usually derived from experimental plots. Low-input field research needs to be conducted for several years to account for the dynamics of weed and pest problems. Until recently, little research of this kind had been done. Four studies using partial budgeting and whole farm analysis are summarized in Table 2. The availability of funding under the Sustainable Agriculture Research and Education (formerly Low-Input Sustainable Agriculture) program of the U.S. Department of Agriculture means that more such studies will likely be reported in the future.

Despite the differing crops, regions, and farming systems studied, the studies sum-

Table 1. Farm surveys of the economics of organic agriculture.

Study	Survey Group	Crop	Average Yield		Yield Differential for Organic Compared to Conventional Crops	Costs	Net Returns
			Organic	Conventional		For organic farms as compared to conventional farms	
			(metric tons ha^{-1})				
Berardi, 1978	10 conventional and 10 organic wheat farmers in New York and Pennsylvania	wheat	2.30	2.96	-22%	Operating costs 23% lower but total production costs 29% higher	75% lower average profits
Oelhaf, 1978	34 organic field crop and fruit/vegetable producers in 9 states and Canada	corn	No data		-15%	10% average increase in production costs	No data
		small grains			0%		
		wheat			-10 -15%		
USDA, 1980	69 organic or organic/conventional farmers in 23 states, and 299 respondents to New Farm (Rodale Press) survey	all types	No data		Comparable to nearby chemical intensive farms	More labor intensive but use less energy	Comparable or lower
Lockeretz et al., 1981	14 matched pairs of organic Corn Belt farms, 1974 - 1976; 23 organic farms, 1977; 19 organic farms, 1978, Western Corn Belt	corn	6.45	7.00	-8%	Operating expenses 6 - 13% lower	Comparable for 1974 - 1977; 13% lower in 1978
		soybeans	2.44	2.57	-5%		
		wheat	1.88	3.28	-43%		

Table 2. Field studies of the economics of low-input agriculture.

Study	Region	Systems	Yield Differential	Costs	Net Returns
			(For low-input systems compared to conventional alternatives)		
Helmers et al., 1986	East-central Nebraska	13 alternative cropping systems for row crops and small grains	7-10% lower for corn and soybeans in 4 year organic rotations compared to 4 year conventional rotations	Not reported	Organic 4 year rotation comparable to 4 year nonorganic rotation
Dobbs et al., 1988	East-central South Dakota	No-chemical input rotations for row crops and small grains compared to conventional and minimum/ridge till systems	5 - 9% lower	Direct costs other than labor 33 - 51% lower per acre	0 - 60% lower per acre
Goldstein and Young, 1987	Eastern Palouse of Washington	Conventional rotation of wheat, barley, peas compared to low input rotation of pea, medic, and wheat	No difference for wheat but 6 - 10% lower for peas	Variable costs ($/acre of rotation/year) 56% lower	More profitable with market prices; less profitable with target prices
Hanson et al., 1990	Pennsylvania	Conventional cash grain rotation compared to low-input grain rotation	33% decline in corn yield during first 4 years but no difference thereafter	Cash operating expense 26% lower per year	8% lower average profit per year compared to conventional system without government programs

marized in Table 2 reported comparable patterns in yields, costs, and net returns. Yields were generally reported as 5-10% lower per acre with low-input systems than with conventional systems. An exception is the study in Pennsylvania, which found corn yields comparable to conventional yields in the later study years. Variable costs per acre were generally reported as lower for low-input systems, although labor and management costs may be higher. Net returns per acre for the organic and low-input systems were usually lower than those from conventional farming systems. However, Hanson et al. (1990) reported data on a whole farm basis and estimated that given a longer transition period than the study time-frame, the low-input system could match the net returns of the conventional system.

Despite the lower profits, some low-input farming systems performed well by other criteria, especially risk. Helmers et al. (1986) concluded that net returns in systems with rotations, including organic treatments, were less variable than most continuous crop systems. Hanson et al.

(1990) found that variation in profits was greater for conventional scenarios than for the low-input scenario studied. If risk aversion criteria are included along with profitability rankings, some low-input systems may perform as well as or better than conventional systems.

Other studies pointed out that changes in farm program benefits can affect the competitiveness of low-input systems (Goldstein and Young, 1987; Dobbs et al., 1988; Hanson et al., 1990; Young and Painter, 1990; Faeth et al., 1991). These studies mostly concluded that current farm programs have worked to the disadvantage of low-input rotations through lack of crop price supports for rotation crops and through base acreage effects. However, important exceptions have been noted (Dobbs et al., 1988; Young and Painter, 1990).

Case studies

An alternative to the collecting and analyzing of farm level data is the case study approach used by the National Research Council (1989) in their report *Alternative Agriculture*. This report summarized 11 case studies to "provide a useful understanding of the range of successful alternative systems available to U.S. farmers" (p. 247). From the case studies, the committee concluded that "farmers who adopt alternative farming systems often have productive and profitable operations" (p. 8). The case study approach has generated extensive comments and criticism (Council for Agricultural Science and Technology, 1990). Systematic research on alternative agriculture is limited, but the case study approach as used in the *Alternative Agriculture* project does not provide sufficient detail about yields, production costs, and net returns of those interviewed to draw conclusions about farm level tradeoffs. The report does demonstrate, however, that specific low-input farming systems may work for some farmers.

Summary of low-input systems

Few studies have explored tradeoffs between agricultural chemical reductions and net farm income at the farm level. Furthermore, the farm level studies reviewed in this paper have several major limitations. First, many focus on the Midwest and row crop/small grain production to the exclusion of other crops in other regions. Regions of the country likely to be severely affected by chemical reductions because of weed and pest problems, such as the Southeast, are not well represented in existing studies. Consequently, extrapolating existing data to represent trends in other regions may be inaccurate.

In addition, the studies as a group focus on "organic" farming or the complete avoidance of agricultural chemicals and fertilizers. Most farms where chemical use has been reduced still use some chemicals (Gianessi, 1990). The analysis of reduced chemical use may be more relevant than organic farming studies.

There is a lack of consideration of management costs associated with adopting low-input agriculture. The National Research Council (1989) report concludes that alternative farming practices typically require more management effort per unit of production than conventional farming. Economic analyses of field data do not include changes in management costs. Surveys and case studies do not control for managerial differences between conventional and low-input farmers.

Finally, the short-term approach of many studies can lead to erroneous conclusions. Most surveys and case studies analyze a single production period. However, some research suggests that year to year weather variables may significantly affect yields and profits in low-input or organic farming. Other research suggests that there may be a biological transition period to organic or low-input adoption (Dabbert and Madden, 1986). At the beginning of the adoption period yields decline, but later they improve. Short-term studies do not account for these impacts.

Despite the limitations of existing research, some tentative conclusions can be drawn from the studies summarized in Tables 1 and 2.

1. Organic farming usually results in lower yields per acre for major crops such as corn, soybeans, and wheat. There is a wide variation in reported yield differences, but no study reported yield declines of greater than 43%, with declines of 7 to 15% reported in most studies. A recent review of yields from organic and conventional farming systems around the world concludes that for a wide range of crops, yields averaging within 10% of those obtained in conventional agriculture have been achieved without the use of agricultural chemicals (Stanhill, 1990). Declines in total crop production may be disproportionately greater than declines in yield, however, because of withdrawal of land from crop production in low-input rotations.
2. Net returns for organic or low-input systems are usually reported as lower than conventional systems. Exceptions are noted, however, for drought years, when longer periods are considered, and for some government program scenarios. Variable costs may be lower for low-input systems, but this may not offset yield reductions and the effects of rotations on total output. Premium prices may keep some organic farmers operational.
3. Organic or low-input systems based on rotations perform well according to risk criteria. Some farmers may be willing to trade net returns for decreased variability in profits.
4. Government programs may influence the profitability of low-input farming systems. Without government programs, some low-input systems could compete effectively with conventional systems. Changes in farm policy could enhance the adoption of some low-input systems in some regions.

In summary, without technology changes or public policy incentives, economics alone would not impel many farmers growing row crops and small gains in the study regions to abandon conventional farming systems in favor of low-input systems. For regions that are not represented in the published research, and where weed and pest problems could be significant, net returns to low-input producers may be even lower for low-input systems than the data summarized in Tables 1 and 2. Nevertheless, some farmers have adopted low-input and organic agriculture in recent decades. Many of these farmers have remained in business despite the farm financial crisis of the 1980s. Their economic and other motives for low-input adoption should be investigated further.

Table 3. Aggregate models of widespread organic farming adoption.

Study	Yield Assumptions	Farm Income	Consumer Food Prices
Council on Agricultural Science and Technology, 1980	15-25% decline for mixed grain/livestock system Source: literature review and expert opinion	Aggregate farm income increases; crop prices increase by 2-4% for every 1% decrease in crop production	Retail food prices increase .75-1.5% for each 1% decline in production
Olson et al., 1982	>50% average decline for wheat, corn, other feed grains, soybeans, and cotton Source: extrapolation of 1944-46 yield data	Increase in national net farm income, but possible regional farm income declines	Increase
Knutson et al., 1990	35% average decline for peanuts, rice, cotton, corn, wheat, soybeans, sorghum, and barley Source: Panel of experts	Average real net farm income increases 100% for crop producers, but decreases 50% for livestock producers. Aggregate net farm income increases 9%	33% increase in Consumer Price Index (CPI) for food
GRC Economics, 1990	27-80% decline for cotton soybeans, wheat, rice, corn Source: literature review and expert opinion	Not discussed	45% increase in CPI for food
Tweeten and Helmers, 1990	As much as 11-22% average decline for corn/grain sorghum, soybeans; 11-25% aggregate output decline Source: Nebraska data	Net returns above variable costs increase by up to 58%	Up to 87% increase in product prices

Aggregate Models of Organic Farming

Farm level studies provide useful information about individual producers' economic incentives for adoption of low-input systems, but they yield little insight into the tradeoffs that might result from widespread adoption. However, information from farm level studies about yields, production costs, and net returns can be used as input into models that evaluate aggregate tradeoffs between producers and consumers through farm income and food prices.

Table 3 summarizes results from studies that have attempted to analyze the implications of widespread adoption of farming without chemicals. Although some studies analyzed several options, for consistency the table summarizes the results of widespread conversion to organic farming (no commercial pesticides and fertilizers). Various modeling techniques and procedures were used, but all studies concluded that widespread adoption of organic agriculture would result in decreased yields and decreased aggregate output, increased farm income, and large increases in consumer food prices.

A critical assumption common to all studies was the yield penalty imposed on producers by organic agriculture. Table 3 illustrates the range of yield reductions and assumptions incorporated into the models. Because of limited research data for some crops and regions, these aggregate modeling studies have relied heavily on expert opinion about yield reductions. It is interesting to compare the assumptions obtained this way to the findings of farm level studies. The decline in national average corn yield, for example, was assumed to be 53% by Knutson et al. (1990), 45% by GRC Economics (1990), and 50% by Olsen et al. (1982). Knutson et al. (1990) suggested that their yield reductions were underestimated, because reduced production due to crop rotation and fallowing were not considered in their model. These expert estimates of aggregate yield loss under organic agriculture adoption appear to bear little relationship to the 7 to 15% average yield changes reported in most farm level studies. Assumptions of smaller yield declines in these aggregate models might dampen the increase in consumer food prices reported in Table 3.

The models summarized in Table 3 have successfully focused attention on the potential sector tradeoffs that can result from changes in agricultural chemical use. However, these models provide only limited information about the exact nature of these tradeoffs. First, as others have noted, such models not only require data about yields and costs that generally are not available by region, but also are sensitive to the assumptions used (Doering, 1990). This means that model results can be questioned if there is legitimate debate over key data assumptions such as yield declines and rotational effects.

Second, the tradeoffs described in Table 3 depend on a complete conversion of U.S. agriculture to farming without chemicals. Such a conversion is not likely, and does not accurately reflect ongoing policy discussions. It may be useful to illustrate the upper limit of potential tradeoffs by analyzing a national ban on chemical, but more realistic analyses of limited reductions in chemical use might change the magnitude or even the direction of the

tradeoffs between farm income and consumer food prices. In summary, while the aggregate models reviewed suggest that farm income and consumer food prices would greatly increase in response to widespread adoption of organic agriculture, these results are not generalizable to other scenarios with more limited chemical use reductions and different yield assumptions.

Recommendations for Future Research

Further research is needed at both the farm and aggregate levels to assess the environmental and economic implications of reduced chemical use for agricultural producers and consumers. The preceding review of farm level and aggregate economic studies suggests the following directions for further work.

• Economic analysis of long-term research data is needed to address the farm level consequences of low-input agricultural adoption for a wide variety of crops and regions.

These studies should consider management costs that may be associated with adoption of low-input agriculture, and where possible provide linkages between changes in farming systems and environmental and health risk variables. Data from projects in the Sustainable Agriculture Research and Education program may allow improved farm level analyses. Integration of economists and physical scientists through bioeconomic modeling efforts may be a promising approach (King et al., 1986).

• Analysis is needed to explain why some farmers adopt low-input agriculture.

Both survey and case study data show that some farmers adopt low-input agriculture successfully. Some research suggests that on-farm health risks of agricultural chemical applications should be considered along with economic variables to analyze farm adoption decisions (Gersh, 1988). Closer scrutiny of the adoption process among low-input farmers could yield insights into factors that mitigate unfavorable economic incentives.

• Models should be developed that allow a broader consideration of the aggregate impacts of adoption of low-input agriculture.

Many questions about the impacts of alternative agriculture cannot be addressed within the framework of existing models (Schaller, 1991). Limited chemical reduction scenarios, consideration of the effects of low-input alternatives on the international competitiveness of U. S. agriculture, and the introduction of environmental and health and safety variables into aggregate models could expand their usefulness. In particular, models are needed that consider potential improvements in human health and the environment along with aggregate farm sector and consumer price relationships. Where possible, aggregate models should incorporate assumptions on variables such as yields and costs that are based on farm level research data. Where there is not feasible, the data limitations of the assumptions should be noted and a range of possible outcomes presented.

• The objectives achieved by aggregate modeling efforts should be reexamined.

The aggregate economic models reviewed in this paper attempt to address the question of the economic impacts of widespread adoption of practices that reduce chemical use in agriculture. From a policy perspective, these models are particularly appropriate for evaluating tradeoffs that might occur if some pesticides were banned nationally, or if pesticide application rates on labels were uniformly decreased across the country. Increasingly, it has been recognized that the environmental effects of agricultural chemical use may vary widely according to soil and climatic conditions and other variables. As a result, policies are emerging that target chemical use restrictions to environmentally vulnerable areas. An example is the Massachusetts wellhead protection program to restrict chemical usage in critical recharge areas around wells. In the current policy environment, states are being given primary responsibility for policy planning and implementation in areas such as water quality. Food safety regulation also is emerging at the state level (Caswell, 1990). These trends suggest that aggregate models that evaluate current chemical use policies should be adapted to focus on targeted solutions and state or regional policies, rather than national chemical use reductions. Although there may be important redistributive impacts from targeted or state level policies, national producer-consumer tradeoffs may be less important. Analysis of alternative national chemical use scenarios can provide useful benchmark information, but may not directly address relevant policy questions.

Conclusions

Despite the incomplete evidence about the risks of using agricultural chemicals, it is generally agreed that human health risks and environmental damages can be decreased through chemical use reductions. Without changes in government programs to provide economic incentives, it is unlikely that many farmers will voluntarily switch to low-input agricultural systems under current conditions. However, state programs are being considered and enacted that may restrict chemical use, particularly in areas potentially vulnerable to environmental damages. The patchwork of policies emerging at the state level may complicate the analysis of benefits and costs. However, these issues need to be addressed by economists to add to public understanding of the potential tradeoffs associated with reducing the use of agricultural chemicals.

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Farm Population Falls by 50% in 20 Years

The number of Americans living on farms has dropped by 50% during the past 20 years, according to a U.S. Census Bureau report. The number of farm residents was 32 million in 1910, and has dropped steadily to 4.5 million in 1990. Today only a third of people employed in farming live on farms, and those who live on their land are increasingly likely to work in occupations other than farming, the report found. It also reported that 51% of U.S. land was employed in farming, down from 57% in 1970. Since 1980, the number of farmers under the age of 25 has dropped by half, while the number of those over 65 has held steady.

Farmers Help Explore Winter Rye as Cover Crop

Seven farmers in seven different states participated in research to determine the effectiveness of winter rye as a cover crop to control weeds in soybean production, in a two-year LISA project. The rye was killed with three different methods and at three different growth stages. The results of participating farmers, in Ohio, Michigan, Missouri, Illinois, Iowa, Nebraska, and Wisconsin, were mixed; several found the rye system did not adequately control grasses.

But at four farms, the system proved effective -- and two farmers are continuing to use it and perfect it to their own unique needs. The use of winter rye to control weeds is now "standard practice" at the farm of Richard Bennet in Napoleon, Ohio; Dick Thompson of Boone, Iowa, has developed his own individual approach and is continuing his own research on the system. For more information, contact James Tjepkema, Rodale Institute, Clarksgrove, MN; (507) 256-7409.

COMMENTARY

Incorporating agroecology into the conventional agricultural curriculum

Miguel A. Altieri and Charles A. Francis

Abstract. *Agroecology is the development and application of ecological theory to the management of agricultural systems, according to the specific land and other resources available. Beyond the biological and climatic dimensions of agriculture and ecology, there is growing appreciation of the influence of social, economic, and political factors on the structure and success of farming systems. This broader field is becoming known as "agroecology and sustainable development." Expansion of the conventional curriculum to include integrative themes is essential because of the need for students to appreciate a whole farm focus for analysis, to understand the impact of socio-economic factors, and to further develop their abilities to link people and environment. Two courses are proposed and described in detail. "Biology of Agroecosystems" includes study of system structure and function, cycles and interactions among components, system development and performance, and the importance of resource conservation and use. "Agroecology and Sustainable Agricultural Development" includes a survey of systems around the world, an evaluation of resources and their use, the environmental impact of agriculture, the relationships between society and agriculture, the applications of agroecology to rural development, and some projections of alternative future strategies for food production. Future agricultural professionals need to understand how improvement of agroecosystems is closely linked to economic, cultural, and political systems, and how they are both enhanced and constrained by factors beyond biology and climate.*

Key words: sustainable agriculture, resource efficiency, cropping systems, agricultural education

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Introduction

Environmental consequences of agriculture in the U.S. and elsewhere have attracted public attention to unintended impacts of some crop and animal production practices. Regulations on use of pesticides, water, and fertilizers present new challenges to producers, who must modify their practices to conform to the goals of a broader society. A major concern today is to maintain a productive and profitable agriculture while eliminating or minimizing the negative long-term environmental and social costs associated with some widely used technologies, such as fertilizers and chemical pesticides (National Research Council, 1989). There is growing awareness that agriculture must compete for scarce resources, and that our current system does not use some of these resources as efficiently as other industries. This competition threatens the sustainability of food production systems (Francis et al., eds., 1990).

One reason that it has been difficult for specialists in agriculture to focus on broader impacts of production systems is our narrow education and training in specific disciplines. We now recognize that challenges in agricultural production and resource use efficiency are more than technical problems. Given a growing appreciation of the impact of agriculture on the environment, it is logical to broaden our horizons in education to include "agroecology." Narrowly defined, this is the development and application of ecological theory to the management of agricultural systems, according to the specific resources available, especially land; agroecology provides a framework within which interdisciplinary activities can occur (Altieri, 1987).

As we examine the multiplicity of complex, interacting, and long-term concerns affecting agriculture, it becomes apparent that even this focus is too narrow. In addition to biological, climatic, and environmental dimensions of food production, there are economic, social, and political

factors operating as well. Agriculture is a biological and ecological activity that interacts closely with the socioeconomic systems that prevail around the globe, and cannot be separated from them (Pierce, 1990). Research, education, and field activities in this complex arena are increasingly being identified under the banner of agroecology and sustainable development (Altieri and Hecht, 1990). It is this perspective that is needed in the education of the next generation of professional agriculturists.

This paper outlines the potential role that agroecology can play in broadening a conventional agricultural curriculum. The goal is to incorporate ecological principles and knowledge into the study of cropping and farming systems, so that professionals are well prepared for the future design and management of a sustainable agriculture. These professionals will need the skills to:

- Enhance agricultural productivity to satisfy food, feed, and fiber needs, increase rural income, and at the same time conserve the natural resource base;
- Introduce ecological rationality and methods into agriculture to minimize chemical inputs and costs, complement watershed and field conservation programs, plan systems according to local resources and land capabilities, and make efficient use of water, nutrients, and genetic resources; and
- Discover long-term policies concerning pricing, taxation, land and resource use planning, research, and educational activities that will promote a stable, resource efficient, and equitable agriculture.

These skills are not readily acquired in today's conventional agricultural curriculum. An application of broad thinking in agroecology can help us design a curriculum to build this capacity in students, making them better prepared to face future challenges in agricultural development.

Agroecological Focus in Education

Most U.S. academic institutions have developed an educational program in the context of capital-intensive agriculture and an infrastructure that provides access to all needed inputs. Both research and education have focused mostly on individual components of a system, such as recommending a specific fertilizer, insecticide, planting date or plant density. Design of courses has followed classical disciplinary lines, with emphasis in any specific course on the soils, the crops, the insects, the plant pathogens, or the water resources. Often there is little attempt to establish the linkages among these components, nor are the complexities of cropping and crop/animal systems made obvious. As we search for ways to control or remediate the most limiting factors to production, our research and education are focused on specific constraints and the yield response to a particular input. Rarely is the goal to study the complex interactions within an ecosystem and its overall productivity (Altieri, 1987).

There is growing recognition of the need to analyze larger units of study than the individual species or even the cropping system in one field. We still appreciate the need to delve in more detail into the integrative processes that govern productivity and sustainability, such as nutrient cycling, water use and balance, energy flow in systems, and competition among crops and pest species. It is equally important to appreciate and analyze larger units of study, such as the total farming system under control of one operator, or the economic and ecological impacts of different input use strategies on a watershed or an effective market region.

Scientific specialization in agriculture has become more a barrier than a bridge for building understanding of complex phenomena or systems. Even when a group of specialists comes together to teach about production systems, an integrated approach is limited by their lack of a common conceptual framework and language. An agroecological approach makes it possible to evaluate and integrate the many disparate elements of agricultural systems into a unified study of how those systems work, and how they affect the biological, economic, and social environment. This approach can help link issues that lie at the interface of ecological, economic, biological, and social systems.

In an agroecological approach to teaching agriculture, there are several ways in which these systems can be conceived:

- Each as a hierarchical system within an agricultural region that is composed of various subsystems (crops, animals, crop/animal systems, whole farm systems, watershed), with vertical and horizontal interactions among those elements or subsystems, and with outputs from one subsystem serving as inputs to other subsystems (Hart, 1980). In a broad sense, the agricultural system is composed of biological and socioeconomic subsystems with inputs and outputs of money, materials, energy, and information. Models of these systems are useful to help students visualize relationships among subsystems and assign values to resource flows among components.
- As a biophysical system with interactions among abiotic and biotic components, emphasizing feedbacks and understanding of cycles, flows, and population fluctuations. The internal structure of an agroecosystem resulting from the assemblage of various components affects the response of the system to different stresses. By focusing on the interdependence of biotic and abiotic processes, it is possible to study and understand how system performance is affected by the infusion or extraction of large amounts of energy, biomass, and nutrients (Gliessman, 1990).
- As a system where management and other decisions by farmers are affected by natural as well as socioeconomic factors. Farmers' perceptions and risk-averting strategies become fundamental to system performance. Indigenous knowledge about plants, soils, environment, and ecological processes gains increased significance within the agroecological approach. Study of how farmers' rationale and technical knowledge can be used within development schemes provides another dimension to the educational process (Altieri and Hecht, 1990).

In summary, the unique nature of education in agriculture using an agroecological frame of reference requires that stu-

dents acquire a broader vocabulary and appreciation of a wider range of information resources that help them understand the linkages among components and the total complexity of agricultural systems.

Specific Methods of Analysis

The move toward an agroecological perspective in education involves an appreciation of a wider complement of methods and components than our conventional approach by discipline. From the descriptive statistics of research results to evaluation of the impact of alternative practices, the methods used by agronomists, animal scientists, economists, and sociologists need to be understood and incorporated. This is one reason for interdisciplinary teaching of an agroecology curriculum. The goals of education in agricultural systems can only be met with approaches that do the following:

- Focus on whole-farm systems rather than using a disciplinary analysis that emphasizes one crop or process; understanding of single crops or processes still is critical to provide building blocks for systems, and these topics also must have high priority in the curriculum.
- Incorporate some sociological methods to evaluate the impacts of both socioeconomic and biophysical production factors on productivity and profitability.
- Use the agroecosystem as the unit of study and concentrate on interactive and integrative processes, such as nutrient cycling, rather than on simple cause-effect relationships, such as corn yield response to levels of applied nitrogen.
- Depend on multidisciplinary teams in teaching, and encourage students to gain the interpersonal skills needed to function well in groups.
- Emphasize the linkages between basic and applied science, between research and development, between people and their environment, and between planning and decision making in agriculture (di Castri and Headley, 1986).

Perspectives on Curriculum Design

As we design a set of courses and a series of topics in each course, it is useful to keep in mind some principles on which agroecology is based and how these influence educational approaches. To present an integrative and practical series of topics and activities, our educational philosophy must be based on the following ideas:

- Transcending the dichotomy of teaching independent courses on agricultural production (technical or discipline-based production sciences) and evaluation of impacts (socioeconomic or impact sciences); emphasis should go beyond limiting factors and focus on system design, performance, and response under a range of circumstances.
- Emphasizing the interdependence and integration of economic, cultural, environmental, social, and technical spheres of interest.
- Studying farms and farm families not as isolated units, but as integral components of communities, watersheds, and a larger socioeconomic system.
- Emphasizing the study of systems at different levels of complexity inherent in agroecosystems; moving from simple cause-effect relationships, we can evolve from a problem-solving mentality to one of "situation improvement" or "ecological enhancement."
- Recognizing the uniqueness of each farm, as well as the need for localized and specific responses that are consistent with the economic, resource, and social environment in which each family finds itself.
- Incorporating students' and farmers' knowledge, innovations, and preferences as part of the total information resource base on which to build improved and sustainable agroecosystems.

The design of a specific course or series of courses depends on applying these ideas to the choice of topics, methods of teaching, and ways of involving students in the process of education. Because of the broad and integrative nature of the subject matter, it is important to explore a wide range of information resources and of ways to integrate them into the classroom and laboratory program.

Components of a Curriculum

We suggest two types of courses as contributions from agroecology that would be appropriate to a conventional agricultural curriculum. As a first step, the topics listed here in two courses could be incorporated into a single course that includes both the structure and functions of agroecosystems and the role they play in sustainable development. Some components could be included in other courses in the curriculum, and additional units could be introduced as appropriate. In developing a comprehensive program, these topics could be expanded into more than the two suggested courses.

First course: Biology of agroecosystems

Structure of agroecosystems: description of different biotic and abiotic components of agroecosystems, different types of regional systems, factors and determinants of productivity, trophic webs, biophysical features of soils, and ecophysiology of plants, animals and microorganisms.

***Agroecosystem functions*:** physiological and ecological processes in agroecosystems (energy flow, water balance, nutrient cycling, trophic relationships, competition, decomposition); ecological and energetic efficiency of agricultural systems; species interactions and role of organisms in agroecosystem processes.

***Development and performance of agroecosystems*:** biological changes and process rates in agroecosystems with time and management; response of different biotic and abiotic components to management; crop responses to multiple factors and different cropping designs and management options; effect of management on microclimate, edaphic factors and species population growth, development, and survival.

***Optimization and conservation*:** how to guide management in a way that promotes beneficial ecological interactions, ensur-

ing productivity, resource conservation, and environmental integrity.

***Agroecological methodologies and mensuration*:** systematization of information on complex interactions in systems, hypothesis formulation, design of on-station and on-farm experiments, establishment of inter-relationships, multi-factorial analysis of data, evaluation of biological parameters, and ecological impacts of agricultural systems.

Second course: Agroecology and sustainable agricultural development

***Agricultural systems of the U.S. and the world*:** biophysical, socioeconomic and management characteristics; development and comparative analysis of systems of varied structures under a range of resource endowment situations.

***Resources available for agriculture*:** relationships among land, energy, population, and other resources and the agricultural potential of different regions; national and regional production trends, policy scenarios, and changes in food demand and distribution.

***Environmental impacts of agriculture*:** pesticide pollution, soil erosion, salinization, eutrophication, water contamination.

***Social and economic aspects of agriculture*:** status of family farms, role and potential dominance of agribusiness, politics of agricultural research, implications of biotechnology and other advances in science.

***Relationships between agriculture and society*:** interactions and issues between urban and rural systems, agricultural technology and public health, gender issues in agriculture, agricultural literacy in total population.

***Concept and dynamics of agroecosystems*:** agriculture as an ecological system; ecological processes such as nutrient cycling, water balance, population regulation.

***Principles of soil management and biology*:** study of major soil types, strategies for providing fertility, physical characteristics as influenced by management, microbiological dimensions of soils and cropping systems.

***Ecology and management of pest populations*:** interactions of crops with weeds, plant pathogens, insects, and nematodes; dynamics of pest populations and effects of different management strategies; genetic resistance or tolerance in crops; interactions of pest populations with fertility, water regime, crop rotations, physical design of cropping patterns.

***Alternative systems of agricultural production*:** multiple cropping, rotations, cover cropping, agroforestry systems, minimum and zero tillage; living mulches.

***Organic farming systems*:** characteristics, management and economic performance; current research results and production trends; conversion studies; marketing system for organic products.

***Agroecosystem analysis and system design*:** diagnosis of field problems, farmers' preferences and experiences; design of technologies and systems tailored to each farmer's needs and resource base.

***Measuring the performance of agriculture*:** economic, resource, and ecological indicators (including social equity, stability of production, sustainability, productivity); accounting for long-term environmental and social costs of agriculture.

Traditional farming systems of the Third World: analysis of sustainable farming systems; ethnoecology of systems; collection and evaluation of indigenous farmer knowledge; studies of subsistence farming systems.

Applying agroecology to rural development in the Third World: use of low-input technologies and local resources; renewable resources and efficiency of small farm systems.

***Challenges and requirements of sustainable agriculture*:** definition of sustainability; technical and social dimensions, policy changes and economic incentives; new directions in research and extension.

***Future of agriculture*:** long-term analysis of agriculture; evaluation of internal and external forces on agriculture; growing role of private sector; North-South issues and other geopolitical questions; global climate change.

Conclusions

We consider it important to incorporate agroecology and sustainability into the educational process in agriculture. The degradation of soils and depletion of other natural resources impose high economic, ecological, and social costs on society in the long term, even though many of these changes are not easily detected or understood in the short term. These impacts of agriculture are occurring despite several decades of applying modern science to improving system performance.

Agricultural professionals need to understand that improvement of agroecosystems is closely linked to interacting economic, cultural, and political systems. National or international economic or policy changes can dramatically influence the options available to individual farmers. Problems of rural development involve more than narrow technical questions; they must be dealt with at the local as well as the regional, national, and international levels.

Awareness of broad socioeconomic and political issues is important for agricultural professionals and should be built into our curricula. Yet a strong ecological and technical science background is still fundamental in agriculture, since improved production practices and rural development involve physical interventions and management of resources. To educate people about the intricacies of sustainable systems requires a broad appreciation of production, of resources, of conservation and environmental impacts, and of the complex socioeconomic goals and factors that influence farmers' decisions. This is the rationale for including a strong complement of agroecology in the conventional agricultural curriculum.

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Book Reviews

Ecological Literacy. Education and the Transition to a Postmodern World. 1992. By David W. Orr. State University of New York Press, Albany. 210 pp. $29.50 hardcover; $14.95 paper.

A book dealing with education pertinent to environmental problems is timely. A recent national survey of college students conducted by the University of California at Los Angeles reported that the environment is the primary concern of incoming freshmen; many universities have responded to this interest by setting up environmental studies curricula. Yet little attention has been given to how interrelations of agriculture and environmental deterioration should be addressed at the college level. A recent review of the federal Sustainable Agriculture Research and Education program (NRC, 1991) said almost nothing about education. It was not even clear whether the education component of this program refers to farmers, other working adults, or students in Colleges of Agriculture or other university settings.

Ecological Literacy is a wide-ranging collection of essays by an author with considerable experience in environmental education. Orr co-founded the Meadowcreek Project, an innovative non-profit environmental education organization in Fox, Arkansas, and now is Professor of Environmental Studies at Oberlin College.

The book is organized into three sections: The Issue of Sustainability; Education; and What Knowledge? For What Purposes? The first section defines the scope and depth of the "crisis of sustainability." It reviews criticism of industrialized societies and literature about detrimental human effects on the biophysical environment. The second section explores ramifications of Orr's belief that "educational institutions are potential leverage points for the transition to sustainability" (p. 84). He argues that sustainability requires changes in the content and process of education, and a "recovery of civic competence" (p. 84). One chapter in this section is an exhaustive syllabus of almost every imaginable topic related to living well and responsibly. The third section deals with a few specific "pathologies of knowledge" (p. 156) that arise from misdirected generation of knowledge. The three examples Orr examines are the assumption that we can manage our planet, the failure of social sciences to contribute to understanding and resolving the crisis of sustainability, and a proposal for a high-technology perennial-based agricultural system from two U.S. Department of Agriculture researchers (Rogoff and Rawlins, 1987). The final chapter includes several alternative visions of the future of U.S. agriculture that contrast with the proposal Orr trounces.

Ecological Literacy is mainly about problems of modern (or perhaps more precisely, "postmodern") industrialized societies, and how education could contribute to solutions. It is related only peripherally to ecology, as most ecologists would understand the term. Orr's syllabus for ecological literacy includes readings by very few professional ecologists, and "ecological literacy" seems to be a misnomer for the concept he promotes. It has more to do with what Orr wants ecology to be than what it is. For instance: "The form and structure of any conversation with the natural world is that of the discipline of ecology as a restorative process and healing art" (p. 91).

Orr pleads for greater understanding of environmental and political issues, and the interconnections between these topics and technical issues, to produce citizens who take their stewardship responsibilities seriously. He tries to link a staggering array of social problems—from terrorism to anomie—with ecological literacy. These connections are the weakest part of the book; they depend too much on idealism and emotional appeal.

I agree with much of Orr's assessment of what is wrong with modern society, but I am unconvinced that his prescription matches the ailments. To me, the basic question for "ecological literacy" is whether greater awareness of social and environmental problems will lead people to be willing to pay the costs of fixing those problems and to forego the benefits of consumerism. This book is a cornucopia of alternatives that could ameliorate the crisis of sustainability, but the jury is still out on what will induce people to choose these kinds of options. Orr's arguments for a rich experiential humanistic education are persuasive, but I think the likely consequences are overstated. (Orr, too, acknowledges that education is only one of several influences on behavior).

The first section of this book adds little to its overall message. Here Orr details the evils of modern society, but they have already been described by the authors listed in his syllabus. Unfortunately, ideas that were plausible in the original sometimes seem fatuous second-hand, when quoted without explanation. For example, it is unclear what Wendell Berry meant by writing that good solutions generically "have wide margins" and "exist in proof" (p. 62). Likewise, the reader might wonder how to use recommendations such as "design should be co-evolutionary" and "design should follow a sacred ecology" (p. 33, quoted from John and Nancy Todd). Perhaps because Orr is trying to cover too much ground, his analyses sometimes seem simplistically distilled into "good

guys versus bad guys," and his solutions sometimes are superficial. He claims that designers of "resilient systems" follow "old precepts such as: KISS (keep it simple stupid); If it ain't broke, don't fix it; You don't put all your eggs in one basket; and, If anything can go wrong, it will, so plan accordingly!" (p. 34). No one can argue with common sense; but if such clichés were sufficient to fix the problems we encounter as a society, we wouldn't be in the mess we're in.

Orr's arguments for an education that equips students to solve genuine problems are passionate and pithy, and he often cuts to the quick of what is wrong with our present-day approach to education. He asks important questions, and wrestles with the answers. His writing often is inspired and capable of catalyzing creativity, but it sometimes verges on cheerleading. His indictment of the social sciences is searing, and his defense of strong democracy with active public involvement by informed citizens is eloquent. But what does it mean to "reinvent politics at the ecosystem level" (p. 70)?

I think many college students will be enthusiastic about the kind of curriculum Orr proposes (although probably not the size of his reading list). The concept of ecological literacy deals with issues that affect their lives and futures, and it goes beyond problems to their possible solutions. Orr wants to nourish the wisdom in students that impels them to plumb the limits of solutions, as they seek appropriate answers to important questions, but these limits are not tested consistently in his book. "Alternative" cant should be scrutinized as diligently as conservative conventional cant, yet only the latter gets drubbed in *Ecological Literacy.*

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Food, Crop Pests, and the Environment: The Need and Potential for Biologically Intensive Pest Management. 1992. Edited by Frank G. Zalom and William E. Fry. American Phytopathological Society Press, 3340 Pilot Knob Road, St. Paul, MN 55121. 179 pp. $34, paper.

This government report, developed by committees, is based on information gathered through surveys. Its organization as a whole is poor, and the writing in individual chapters is mediocre at best. However, the existence of the book is significant in its implications for future directions in mainstream pest control in America. Furthermore, many interesting statements scattered throughout the text are well worth reading.

The merits of the book are twofold. First, it gives official sanction to the view that IPM methods in the future will need to do much more than use pesticides efficiently; its central premise is that for many pest problems, Integrated Pest Management schemes for crops will have to substitute other controls for chemicals. The book assesses the potential for such substitutions both for methods that have been developed already (such as biological control, plant breeding, cultural control, and genetic manipulations), and for those that are under study. It does this for several classes of pests, including arthropods, weeds and plant diseases, for crops such as soybeans, corn, cotton, tree fruits and vegetables. In some chapters, such as the one on cotton, the possible future form of such "biologically intensive IPM" is made tangible for the reader through a verbal portrait, describing the features that might make up such a system. In other chapters, such as the one on tree fruits, a more detailed approach is taken, with a pest-by-pest tabular listing of future alternative controls. Of the two, I found the former livelier and more likely to engage the imagination. Unfortunately, most of the book cannot be described as either lively or engaging of the imagination. Thus it loses an important opportunity to promote biologically intensive pest control by helping readers visualize the pieces of such a system. Nevertheless, the report points us toward biologically intensive IPM systems and gives details on many of the barriers that must be removed to implement it.

The second merit of the book lies in the many important statements that describe where the path to biologically intensive IPM lies, and what obstacles stand in the way. Some of these are about problems specific to the crops under discussion; others deal with general problems that affect IPM in all crops. I found that the vegetable chapter made good use of examples, and escaped somewhat from the excessively general statements that are common throughout the book.

The book also makes many important statements on broad issues. I particularly liked the following:

- A major challenge for the future will be the management of entire pest populations on an area-wide basis.
- The predominant role of [Cooperative Extension] IPM Specialists will be to train the Crop Practitioner Doctors.
- Pesticide Applicator Training programs conducted by CE should be restructured to include or even emphasize biologically intensive IPM methods.
- Resources directed to "chemical systems" commonly exceed $40 million for the registration of a single pesticide. This level of funding is not available for all biological control research nationally.
- [We should] develop a plant health prescription policy to dissociate chemical sales from the recommendations of materials.
- [We need] new or modified control action thresholds which incorporate population levels of beneficial organisms.
- The price of pesticides could be increased to reflect their expense in terms of regulatory expense and social and environmental costs.

For the sufficiently persistent reader, many such interesting and significant statements can be dug from the text. They deserve to be developed in a thoughtful, comprehensive way. Regrettably, few are, which brings us to the books defects.

The book suffers from poor overall organization, inadequate development of subjects within chapters, and bad writing in many sections. It consists of an introductory chapter, four chapters covering

specific crops, and a summation chapter. This may seem a reasonable organization, but it severely detracts from the logical treatment of the book's subject. Many of the issues addressed are generic, rather than crop specific. Consequently, with chapters defined by crops rather than issues, many broad issues are raised over and over in two, three, or even four chapters. This duplication is disorienting, and detracts from the discussion of the main points of the book. The chapter structure is not dictated by the logic of the subject matter, but rather is a result of how information was collected (surveys of commodity specialists).

Within chapters, material in many sections is presented as short, independent statements set off by "bullets". These lists greatly detract from the book because they have replaced the normal task of writing, in which ideas are organized around a series of major and minor points developed with logic and examples. In many sections, no such development is even attempted. Rather, lists are presented, grouped into sections by broad topic. The order of items within lists apparently was not considered important, and many items could have been left out or replaced by others without significantly influencing the text. The affect is numbing. Instead of paragraphs that make points and guide and persuade the reader, we are confronted with unsorted piles of ideas. This is unfortunate, since many of the ideas are good, and deserve to be developed and expounded more fully. Unfortunately, often this was not done.

The third area in which the book needs improvement is writing. Some chapters are marginally better than others, but much of the book reads like spoken rather than written language, with grammatical errors, poor phrasing, and poor usage, such as "impact" and "interface" as verbs.

Despite these faults, the book draws together, albeit loosely, many significant ideas about the road towards biologically intensive IPM. As an organized banquet it fails, but as a smorgasbord, it serves richly.

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Nitrate Pollution Widespread in Parts of Michigan, Says Report

Nitrate contamination of drinking water is widespread through the heavily populated and heavily agricultural regions of southern lower Michigan, according to a report by Clean Water Action and Clean Water Fund of Michigan.

"New studies confirm a growing number of Michigan areas in which nitrates exceed federal drinking water standards," says the report, entitled "Poison in the Wells: Nitrate Contamination and Michigan's Water Resources." Nitrate levels are lowest in central Michigan, but high in southern and especially southwestern lower Michigan in recent years, the study found.

The single greatest source of nitrate contamination is believed to be farming, with animal waste runoff and storage, and excessive application of fertilizers the principal agricultural causes, the report says. "The average [application of nitrogen fertilizer] per acre of corn land rose between 1965 and 1980 from 74 to 135 pounds," it reports.

"Concerned about the failure of the state to devote resources to analyzing the thousands of test results it derives each month from testing of private water wells," Clean Water Fund requested lab results from the Michigan Department of Public Health for the month of January, 1992.

Of those private wells, 46.7% tested positive for nitrates. The vast majority of the positive results tested between zero and five parts per million, with 10 parts per million being the federal EPA allowable standard for nitrate in drinking water. Levels that exceeded that federal standard were found in 2.4 percent of the total samples.

"Attention of federal and state agencies and university researchers is now focusing on Cass County in southwest Michigan, whose combination of intensive agriculture, clusters of septic tanks, and porous soils are showing some of the most nitrate-contaminated drinking water ever found in Michigan," the report said. "Wells tested in and around Donnell Lake in that county showed nitrate levels as high as four times the federal drinking water standard."

Infants under the age of three months and pregnant women are particularly at risk from nitrate contamination in drinking water, according to the report, which also said high nitrate levels are also suspected to be linked to an increased risk of cancer.

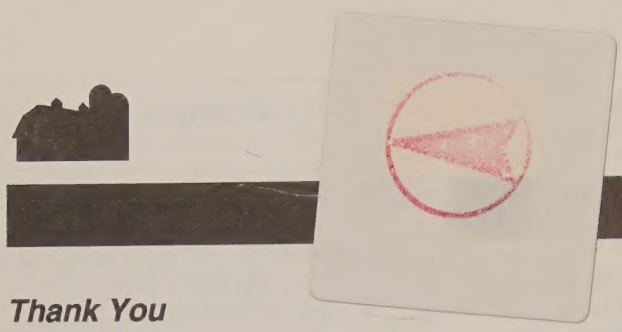
"Poison in the Wells" is available from Clean Water Action, 122 South Grand, Suite 200, Lansing, MI 48933; (517) 487-9534.

Natural, Organic Foods Find Increasing Shelf Space

The natural and organic foods industry is making small but steady progress nationwide, according to a four-page article in the June issue of **In Business**, a magazine for environmental entrepreneuring. Of the country's 6,000 natural food stores, some are beginning to resemble conventional supermarkets; in addition, organic foods are increasingly appearing in supermarket chains, according to the article.

"The price of organic produce has fallen 20 to 25 percent, but the total value of sales has remained constant, indicating a major increase in the amount sold," it reports. Natural foods retail cooperatives have thrived in the past 20 years, while most of the conventional cooperatives have failed, according to **In Business**.

The organic distribution system is improving in many areas of the country, according to the article, and many believe the implementation of the Organic Foods Production Act scheduled for the fall of 1993 will improve the market.



Thank You

Perhaps the single-most frequent comment received here over the past several years regarding this institution's contribution to sustainable agriculture, is that we produce a journal of the highest professional calibre. This observation, of course, derives in large measure from the high standards to which our reviewers hold all submissions to this publication. It is heartening that these professionals listed below continue to give so unstintingly of their time and talents to ensure that our field is well informed. Once again, I extend my deepest thanks to our colleagues and friends who have done so much to move the debate forward, and whose partnership in our work is invaluable.

Garth Youngberg
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Research papers should use the International (SI, or metric) stem throughout. Occasional use of common unit equivants in parentheses is permitted, mainly for relatively exotic units.

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The entire manuscript, including abstract and references, should be typed on one side of standard-size paper, double spaced, with margins of at least one inch all around. Starting with the title page, label all pages in the upper righthand corner with the lead author's last name and the page number. Do not use hyphens unless the hyphen is part of the word.

Follow the section headings style used in this AJAA issue. All headings are flush left, with no underlining or italics.

Tables should fit on one page, be numbered consecutively with Arabic numerals, and be on a separate sheet. Leave extra space to separate columns. Every figure and table should be mentioned at least once in the text.

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How you can help support the scientific and educational needs of a sustainable agricultural system

A growing number of Americans have become concerned about the long-term sustainability of our food production system. Farmers and agricultural scientists are among those raising questions about the growing dependence of modern farming on nonrenewable resources, the depletion of our resource base through soil erosion, and heavy reliance on chemical fertilizers and pesticides. Continued heavy reliance on farm chemicals is questioned because they have become an expensive production input. Their widespread use also raises questions about human and animal health, food quality and safety, environmental quality, and the continued demise of the family farm.

Low-input alternative farming methods address these economic and environmental challenges. Alternative production systems point the way toward more profits, more individual choice, and long-term sustainability for our food system. More must be done to develop effective ways to make sure research, education, and information sources are readily available to farmers who want to adopt these techniques.

The Institute for Alternative Agriculture needs your help in meeting this challenge. We are a nonprofit tax-exempt research and education organization set up in 1983 to encourage and facilitate the adoption of low cost, resource conserving, and environmentally sound farming methods. We work directly with government agencies, colleges and universities, producer groups, and other institutions that provide research, education and information services to farmers.

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